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THE RELATIONSHIP OF WEATHER FACTORS TO THE RATE OF SPREAD OF THE ROBIE CREEK FIRE

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ABSTRACT

The Robie Creek Fire in Boise National Forest, Idaho, September 5–9, 1955, is described, and concurrent weather conditions are analyzed. The fire exhibits four different types of behavior during the five days. On four of the days, the behavior follows patterns previously recognized as being usually associated with the prevailing weather conditions. The exceptions occur on the third day, which is meteorologically similar to the second day but exhibits a different fire behavior. Some implications that this study has for forecasting and research are pointed out.

1. INTRODUCTION

Many observations have been made regarding the cause of forest and range fire spread and a number of well-qualified men have made investigations and contributed valuable reports and technical papers on this complex subject. There is general agreement that weather is the most important variable in fire spread, and that the conditions which lead to "blow-ups" are very complex and difficult to predict.

This paper consists of a report of the weather conditions which existed during the Robie Creek Fire in the Boise National Forest, Idaho, September 5–9, 1955, and an analysis of the relationship of those conditions to the fire behavior.

There are several reasons why this fire adapts itself to an analysis of this type: (1) The fire occurred only 10 to 15 airline miles northeast of the Boise Weather Bureau Airport Station where regular surface and upper air observations are made. (2) The fire area was bracketed by two fire-weather stations, Shafer Butte Lookout, six miles north of Robie Creek at an elevation of 7,590 feet, and Idaho City Ranger Station some 12 miles northeast of the fire, at an elevation of 3,950 feet, in the main Mores Creek Drainage. (See fig. 1.) (3) The fire went through four different types of behavior-day: a blow-up, a long run, a potentially critical but quiet day, and a quiet day.

2. DESCRIPTION OF THE FIRE

The Robie Creek Fire in the Boise National Forest started in the early afternoon of Labor Day, September 5, 1955. It was a hot, dry day; the 45th day since there was measurable precipitation in that area and the 21st consecutive day with the maximum temperature above normal. The maximum temperature at nearby Idaho City Ranger Station that day was 101° F. and the relative humidity was 6 percent resulting in a very high fire danger (Burning Index of 72 on the Forest Service Model 8 Meter).

The fire apparently started on the east side of the Boise Ridge and at a point on a minor slope exposed to the southeast. The point of ignition was in well-cured grass in a light stand of chokeberry brush. Fuel in the general area consisted mostly of dry grass, several kinds of brush, and second growth Ponderosa pine. The fire started at an elevation of about 5,000 ft., but eventually spread over an elevation range from 4,000 to 5,500 ft. Although winds were light and variable, the other factors were very conducive to fire spread. Within two hours of the time that fire began there were 15 to 20 people from the nearby

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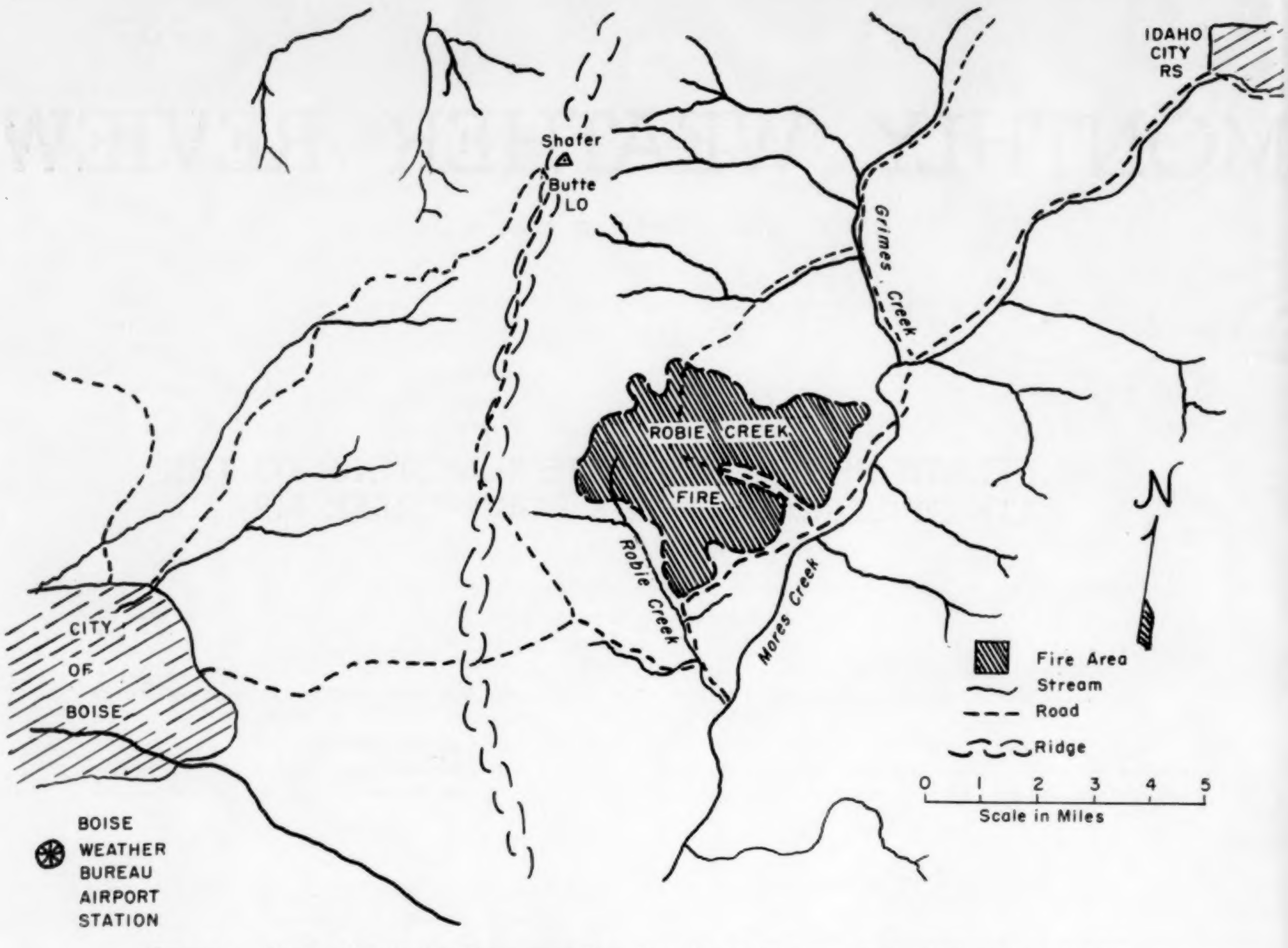

FIGURE 1.—Sketch of general region surrounding Robie Creek Fire area, Boise National Forest, Idaho.

FIGURE 2.—Total area of the Robie Creek Fire showing location where fire started on Monday, September 5, 1955 and its spread on succeeding days. Grid interval equals 1 mile.

Karney Lakes Resort, four smoke jumpers, and a crew of 20 trained fire fighters at the scene, but the rate of spread was so great that the fire fighters had to retreat from the fire area.

The fire started on Monday, September 5 and was brought under control on Friday, September 9. Of the five days, major runs or "blow-ups" occurred on three days: Monday, Tuesday, and Thursday. On Wednesday there were minor flare-ups, but no sustained run occurred. There was very little spread on Friday as established lines were widened and mop-up commenced (see fig. 2).

During the five days the fire spread over 8,310 acres of private and National Forest land. At the peak of the attack over 700 men were employed and total suppression costs were in excess of $100,000.

3. WEATHER CONDITIONS

In the attempt to determine which weather parameters had the most influence on the fire behavior during the 5-day period, comparisons were made of the various weather data.

On the assumption that stability would be an important factor, a comparison was made of the twice-daily Boise radiosonde observations (fig. 3). The lapse rate was very nearly dry adiabatic on Monday, Tuesday, and Wednesday and only slightly more stable on Thursday and Friday. Since the fire made big runs on Monday, Tuesday, and Thursday it appears that something more than stability was involved. On Thursday when the fire made one of its largest runs the lapse rate was less than on the preceding three days. The daily lapse rates were compared by layers but nothing of significance was indicated.

Another approach to the stability factor was made by plotting the Shafer Butte, Idaho City, and Boise WBAS maximum temperatures on the appropriate tephigram at the proper temperature and elevation point. (See fig. 3.) On Monday and Tuesday the temperature at both Shafer Butte and Idaho City was considerably warmer than that shown at corresponding levels on the 2000 MST Boise radiosonde observation. On the assumption that the Boise sounding was representative of the air over those two stations (see fig. 1), superadiabatic lapse rates apparently existed near the surface at the two stations. On Wednesday and Thursday this apparent superheating effect was considerably reduced.

Comparison was also made between the Shafer Butte and Idaho City 1600 MST relative humidity and maximum temperatures for each of the days, but other than to show that it was hot and dry all five days the significance in relation to fire spread was not readily apparent. (See table 1.) The maximum temperatures were highest on Monday and Tuesday, about 8° lower on Wednesday, and 5° to 10° lower still on Thursday and Friday. The afternoon relative humidity was low throughout the period ranging from 6 percent at Idaho City on Monday, to 12 percent on Tuesday and Wednesday, up to 26 percent on Friday. The Shafer Butte relative humidity varied from 11 percent on Monday, to 14 percent on Tuesday and Wednesday, up to 40 percent on Friday.

The wind speed profiles for the 0800 MST and 1400 MST Boise winds aloft observations are shown in figure 4. The wind speeds above 7,000 ft. m. s. l. increased gradually during the first four days of the fire and then slacked off again at the end of the week. The winds aloft show a closer correlation to fire behavior than any of the other factors and that relationship is discussed later in connection with Byram's Wind Speed Profile Types.

TABLE 1.—*The maximum temperature and 1600 MST relative humidity for the five days of the Robie Creek Fire, Boise National Forest, Idaho*

		Monday 9/5/55	Tuesday 9/6/55	Wednesday 9/7/55	Thursday 9/8/55	Friday 9/9/55
Boise Weather Bureau Airport Station	Max	97°	98°	97°	81°	80°
	R. H.	24%	23%	17%	27%	30%
Idaho City Ranger Station	Max	101°	100°	92°	80°	81°
	R. H.	6%	12%	12%	19%	25%
Shafer Butte	Max	84°	83°	77°	62°	62°
	R. H.	12%	14%	14%	34%	40%

4. FIRE BEHAVIOR

The fire behavior on Monday was very similar to that of Tuesday and most of the weather data were strikingly similar on those two days, except for minor changes in the winds aloft patterns. The fire covered considerably more acreage on Tuesday than on Monday, but that difference was probably due to the fact that the fire started from zero area on Monday afternoon while it was well established with several miles of front on Tuesday. See figure 2. Monday and Tuesday both had some of the characteristics associated with a blow-up pattern; i. e., steep lapse rates, high temperatures, low humidity, dry fuel, and relatively light winds aloft. On both Monday and Tuesday the major spread occurred in the middle and late afternoon and was accompanied by a nearly vertical smoke column which was topped by a well-developed cumulus cloud (see fig. 5). Both Monday night and Tuesday night the smoke filled the surrounding valleys and remained low until upslope motion commenced at 1000 MST on Tuesday and 1100 MST Wednesday.

On Wednesday the fire spread over only about 500 additional acres compared to over 3,000 acres on Tuesday. However, the temperature lapse rate was almost as steep as on the previous two days and the minimum relative humidity at Idaho City and Shafer Butte was the same as on Tuesday. There were minor changes in maximum temperature with a drop of 6° at Shafer Butte and 8° at Idaho City. Winds aloft were weaker at low elevations and stronger at high elevations as shown by the wind speed profiles. On Wednesday there was no towering cloud-capped smoke column, only small areas of billowing smoke during the afternoon. In contrast to the previous nights the fire continued to spread during the night, especially near the ridge tops, and there was very little smoke hanging in the valleys Thursday morning.

On Thursday cooler air was obviously moving into the fire area with moderate westerly winds across the Boise Ridge and down onto the fire. In the early morning the fire was moving rapidly up the slopes exposed to the west and throughout the morning and afternoon the fire continued to spread in an easterly direction. Maximum temperatures were down about 20° from Tuesday and minimum relative humidity was up 10 percent to 20 percent. Although the fire covered nearly as great an area on this day as on Tuesday the behavior was different. The wind was relatively consistent in both speed and direction and the fire moved from west to east, up slope and down. The forest officials described it as more of a steady "push" than a blow-up. The smoke column leaned to the east and although small cumulus tops appeared frequently they disappeared almost as quickly as they formed. See figure 6.

On Friday winds were light and variable, temperatures were about the same as on Thursday, and the relative humidity was higher by 5 percent to 10 percent. In the

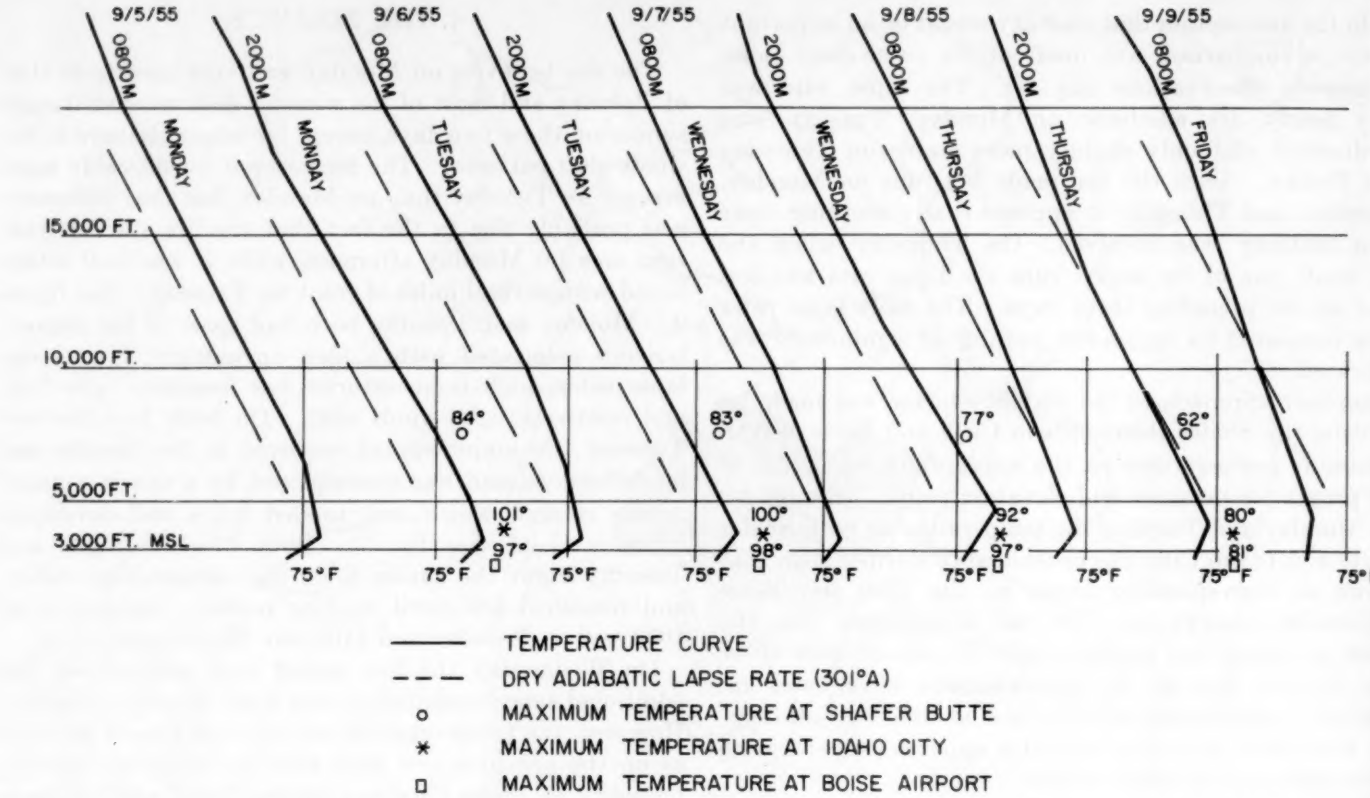

FIGURE 3.—Radiosonde temperature observations at Weather Bureau Airport Station, Boise, Idaho during period of Robie Creek Fire. Daily maximum temperatures for Shafer Butte Lookout, Idaho City Ranger Station, and Boise Airport are plotted at their relative elevations.

afternoon a few minor dust whirls (fig. 7) were visible in the ashes and smoke stumps, but at no time was there a serious flare-up or threat to the fire lines. By this time the suppression attack was organized and lines were well-established and manned. However, portions of the line would probably have been vulnerable to a strong wind or blow-up development.

5. DISCUSSION

There is considerable difference in opinion among fire control experts as to just what constitutes a "blow-up". Definitions range from an actual explosion of hot gases, to a fire that is merely burning out of control. Arnold and Buck [1] define blow-ups as "fires which exhibit violent build-up in fire intensity or rate of spread sufficient to prevent direct control by efficient application of conventional fire fighting methods." By this definition conditions that could be classed as blow-ups occurred in the Robie Creek Fire on Monday, Tuesday, and Thursday, although the associated weather conditions and fire behavior were not the same.

On the first two days the smoke column went almost directly upward and the cumulus cloud cap continued to build and spread until dissipation set in at sundown. There appeared to be a "chimney effect" reaching to an estimated 25,000 to 30,000 ft. which induced a strong draft at the base of the column. Wind speeds in the free air at Boise were 9 to 12 m. p. h. at the fire level and at Shafer Butte the speed at 1600 MST was estimated at 8 m. p. h. on Monday and 14 m. p. h. on Tuesday.

As previously mentioned, the spread on Thursday was from west to east with the smoke diffused over a wider area and with a definite slope to the smoke column. Winds in the free air at fire levels were from the west 14 to 22 m. p. h. and at 1600 MST Shafer Butte reported southwest 20 m. p. h.

Arnold and Buck [1] have listed five atmospheric situations under which fire blow-ups may occur:

1. Fire burning under a weak inversion.
2. Fire burning in hot air beneath a cool air mass.
3. Combustible gases from a fire accumulating near the ground.
4. Fire exposed to a steady-flow convection wind.
5. Fire burning near a cell of vertical air circulation.

The rapid spread on Monday and Tuesday corresponded to situation 5, and the conditions on Thursday seemed to fit situation 4.

Byram [2] states that for the greatest blow-up potential the wind should reach a maximum within the first 1000 ft. above the fire and then decrease in speed with elevation for the next several thousand feet. He refers to this point of maximum wind speed immediately above the fire as the

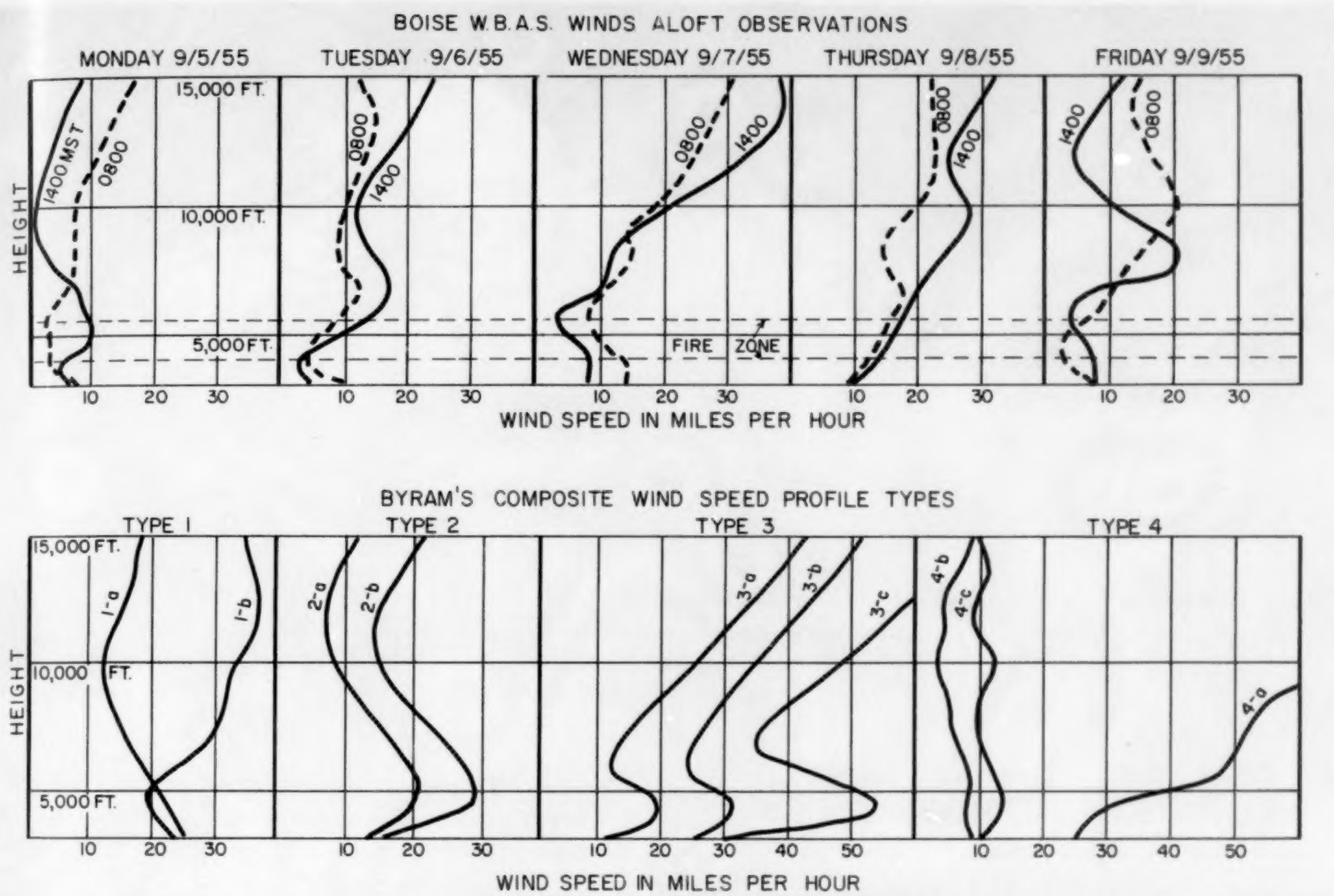

FIGURE 4.—Daily winds aloft observations taken at Weather Bureau Airport Station, Boise during period of Robie Creek Fire (upper graphs) compared with Byram's wind speed profile types.

"jet point" and states that the wind speed near the jet point for most dangerous fires will be 18 to 24 m. p. h. for light to medium fuels. Byram has classified the wind speed profiles into four main types, each with two or more sub-types (see fig. 4).

In comparing the wind speed profiles of the 1400 MST Boise winds aloft reports for the five days of this discussion we find that the profile for Monday closely resembles Byram's Type 4-c which ". . . is 'safe' as long as the jet point wind is below 15 m. p. h. . . . except in case of a fire burning up slope in same direction as general wind is blowing in which case 4-c may be converted to the dangerous Type 1-a." Although the wind on the Robie Creek Fire was below the mimima listed by Byram, the fire was burning up slope with the wind and it had many of the characteristics of his Type 1-a.

The wind speed profile at 1400 MST on Tuesday for Boise closely resembles Byram's Type 3-a with the jet point just above the fire zone. This type has strong winds at high levels, but with a layer of decreasing speed just above the jet point. Byram says of this particular profile ". . . for a fire near 7,000 feet it resembles the dangerous Type 1-a and it is doubtful if the wind speeds at high levels are strong enough to shear off the convection column." Type 3-a and 3-b may be accompanied by strong whirlwinds and rapid fire spread when jet point winds are 20 m. p. h. or more. The winds at the jet point level at Boise Weather Bureau Airport Station were below Byram's minima, but speeds must have been higher just above the fire. Fire crews reported "spotting" as much as a quarter of a mile ahead of the fire Tuesday afternoon which would indicate some of the whirlwind activity mentioned by Byram.

On Wednesday the wind speed profile resembles Byram's Type 1-b, except that wind speeds in the fire zone were much below the limits shown. The strong winds above 10,000 ft. would tend to prevent formation of a convection column which might induce strong winds at the surface. Colson [3] states ". . . the convection column will not attain great heights if the wind speed increases too rapidly with height. Too strong a wind speed may cause the column to be broken away from its energy source."

Byram's Type 4-a resembles the wind speed profile and also the fire behavior on Thursday. Regarding Type 4-a Byram states ". . . fires were intense and fast-spreading, but they could not be considered dangerous to experienced crews, nor was there any erratic and unusual aspects to their behavior." On the 1400 MST profile there was a jet

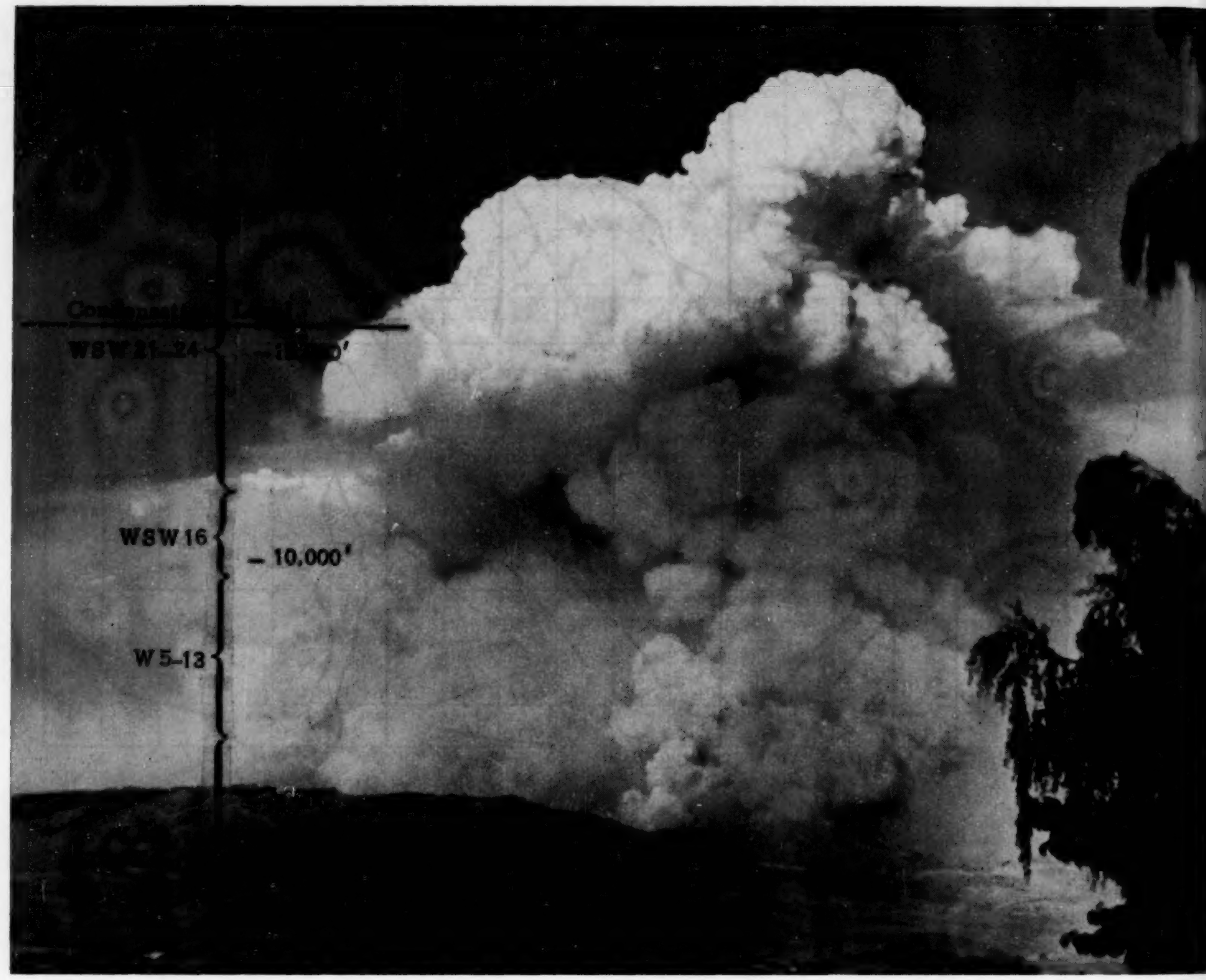

FIGURE 5.—The cloud-capped smoke column of the Robie Creek Fire as viewed from the Union Pacific Depot in Boise, Idaho looking east-northeast at approximately 1800 MST, September 6, 1955. The ridge in the foreground varies from 5,000 to 6,000 ft. m. s. l. and the top of the cloud was estimated from theodolite readings to be near 25,000 ft. The height scale on the picture is compressed some near the top to compensate for the slope of the smoke column and cloud away from the camera. Wind velocity and condensation level shown are taken from the 2000 MST rawin observation made at Boise Airport. (Photo by Russel M. Short.)

point at 10,000 ft., but it was too far above the fire area to develop the characteristics of Byram's Types 2 or 3.

The speed profile at 1400 MST on Friday closely resembles Byram's Types 1-a or 2-a for the area above 7,500 ft., but fortunately the fire zone was below 5,500 ft. where the winds were light.

In this application of Byram's Wind Speed Types to the Robie Creek Fire we have not considered wind direction and in most cases actual wind speeds were below those specified for his types. His classifications explain the fire behavior during most of the fire period, but from the forecaster's standpoint it would be difficult to predict some of the minor differences among these types.

The fire behavior on Monday, Tuesday, Thursday, and Friday followed previously recognized patterns usually associated with the prevailing weather variables. However, the meteorological similarity between Tuesday and Wednesday was remarkable while the fire behavior was very different. Following is a comparison of the two days:

1. Fuel conditions on Wednesday were essentially the same as on Tuesday with fuel remaining on all sides of the fire. Lines had been established on some of the fire boundary, but the long run the following day indicates that the spread potential was present.

2. Figure 3 indicates that stability was not the differentiating factor.

3. Minimum relative humidity was the same both days.

FIGURE 6.—Looking southeast toward the Robie Creek Fire from near Shafer Butte Lookout, Thursday, September 8, 1955 at 1715 MST. Note smoke column leaning toward the east. (Photo by John H. Dieterich.)

FIGURE 7.—Dust whirl in ashes behind fire lines near a ridge top. Robie Creek Fire, Friday, September 9, 1955 at 1410 MST. (Photo by John H. Dieterich.)

4. Maximum temperatures were the same at Boise and 5° to 8° lower at Idaho City and Shafer Butte on Wednesday, but that change in itself hardly seems great enough to be critical.

5. The winds aloft at Boise Weather Bureau Airport Station show minor differences in direction on the two days, but wind speed profiles (fig. 4) varied considerably. Byram's wind speed profile types are different for the two days and they offer probably the best explanation for the variation in fire behavior between the two days.

6. A study of the pattern of the maximum temperature distribution between Boise Weather Bureau Airport Station, Idaho City Ranger Station, and Shafer Butte Lookout shows another difference between Tuesday and Wednesday. See table 1.

When the maximum temperatures were plotted on the tephigram with the Boise radiosonde observations (fig. 3) it appeared that there must have been a super-adiabatic lapse rate near the surface at Idaho City and Shafer Butte on Monday and Tuesday which was not nearly so pronounced on Wednesday. This super-heating effect was at a maximum on Monday and Tuesday, was at a minimum on Wednesday, and gradually increased again on Thursday and Friday. Surface winds at the three points do not explain this difference, nor were there any obvious differences in microclimatic effects at the different exposures. There currently seems to be no ready explanation for those variations in super-heating, but that factor did vary with the rate of spread of the Robie Creek Fire.

6. CONCLUSIONS

Monday and Tuesday, the first two days of the Robie Creek Fire, were examples of the convective-column type blow-up days with light winds, steep lapse rates, high surface temperatures, and critical wind speed profiles.

Fire behavior on Thursday was an example of a long fire run resulting from a strong and persistent horizontal wind accompanying the advection of cooler air into the fire area.

Friday was a day with unstable lower layers and light wind at critical levels, but with no spread difficulties encountered on the fire lines. Wind whirls were visible in the ash and smoke in some areas inside the fire lines and conditions of wind, temperature, and stability fit closely most of the conditions favorable for fire whirlwinds as described by Graham [4] and Byram [2]. Fortunately the whirlwinds did not occur in the vicinity of hot fire and heavy fuel.

Fire behavior on Wednesday does not fit into the accepted pattern usually associated with the prevailing

conditions of temperature and stability, but, as indicated by Byram, the wind speed profile was one that would favor fire control with light winds in the fire zone and strong winds at high levels.

Presently there is no satisfactory explanation at hand for the differences in the maximum temperature distribution pattern between Boise, Idaho City, and Shafer Butte. Since this temperature pattern did appear to vary with the rate of fire spread, a logical explanation might serve as a forecasting aid.

The principal objective in an analysis of this type is to develop means of improving forecast and warning techniques. Byram's wind speed profiles have considerable merit, as the evidence has shown, but a careful examination of the wind speed profiles for the 0800 MST wind observations indicates the presence of a "jet point" on each of five days. On Monday, Wednesday, and Friday the jet point moved down 1,000 ft. or more between 0800 MST and 1400 MST while on Thursday it moved up 3,000 ft. and on Tuesday it remained at the same elevation. From a forecaster's standpoint it would be difficult to separate the blow-up days from the quiet days on the basis of projected 0800 MST wind speed profiles, although this is a field in which further study seems warranted.

This study indicates that the forecasters on large fires should consider carefully the wind speed profiles and surface temperature distribution as well as temperature lapse rates, surface weather charts, and other observational material. If it were possible to dispatch a mobile rawinsonde observational unit to large fires the information gained would be very valuable to the forecaster in predicting fire behavior. The cost of constructing and operating a mobile rawinsonde unit would be considerable, but in view of the terrific property losses and suppression costs on large fires, such a unit would be justified. Pilot balloon observations would be impractical because of visibility restrictions, and only very rarely does a large fire occur close enough to an upper air observational station to make the data representative of conditions over the fire.

ACKNOWLEDGMENTS

Our thanks to George M. Byram and Charles C. Buck of the U. S. Forest Service and to DeVer Colson of the U. S. Weather Bureau for their reviews and comments on the first draft of this paper. Our thanks also to the staff of the Boise National Forest for their patience in answering questions and supplying data.

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Mariners Weather Log

A new bi-monthly publication containing meteorological information for the maritime industry, including weather and shipping on the Great Lakes as well as oceanic areas, recently began issuance under the title *Mariners Weather Log*. The first issue was dated January 1957. Each issue usually contains two major articles and several smaller contributions of current maritime interest. Recent ocean weather is described and a table of selected ship gale observations is included. Annual subscription, $1.00; additional for foreign mailing, 25¢; 20¢ per copy. Orders should be addressed to Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.

PRECIPITATION RATE AS A FUNCTION OF HORIZONTAL DIVERGENCE

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There is much current interest in the relationship between horizontal velocity divergence and precipitation rates, as well as the relationship with such phenomena as tornadoes. This widespread interest suggests that forecasters and synoptic meteorologists need to acquire a quantitative idea of the magnitude of convergence associated with precipitation rates. The purpose of this paper is to present such relationships based on a fairly realistic model.

The rate of precipitation from a layer of saturated air ascending pseudo-adiabatically was derived by Fulks [1] who used vertical velocity as his basic parameter. Conversely, Bannon [2] used precipitation rates to estimate vertical velocities of the air. Because measurements of

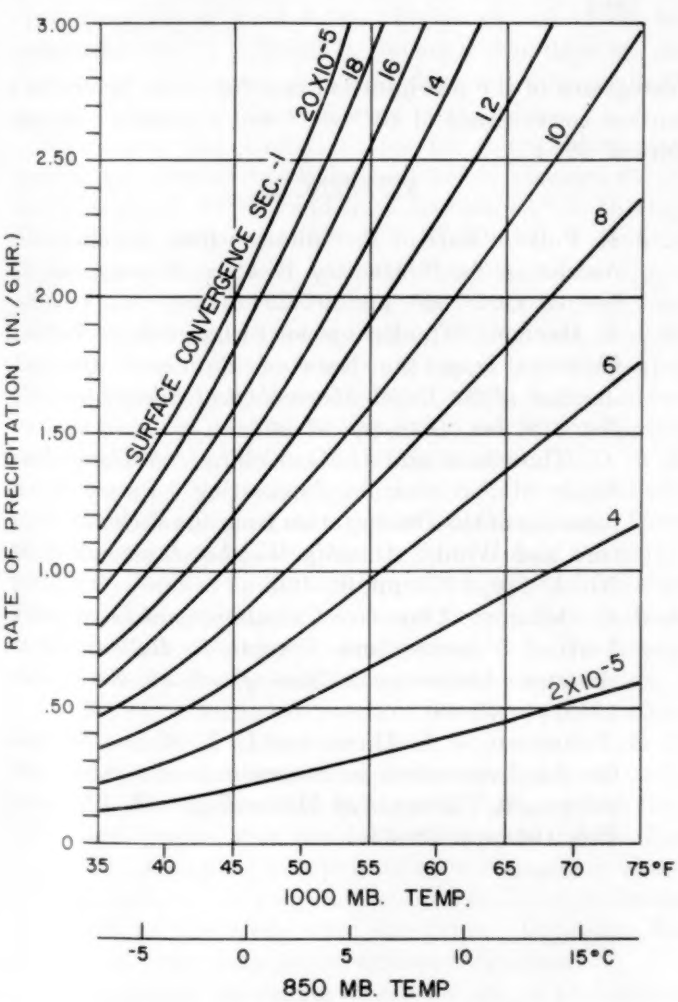

FIGURE 1.—Rates of precipitation from pseudoadiabatically ascending air, assuming constant convergence with height. Convergence values expressed in sec^{-1} may be multiplied by the conversion factor 0.036×10^5 to obtain convergence expressed in hr^{-1}.

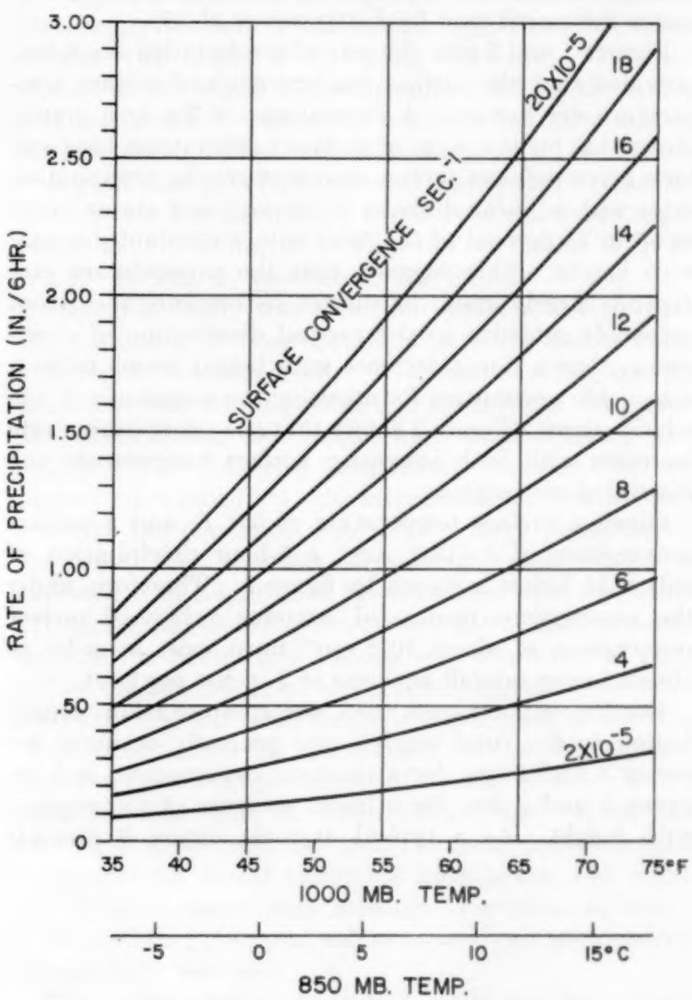

FIGURE 2.—Rates of precipitation from pseudoadiabatically ascending air, assuming a linear decrease of convergence with height to Div $\mathbf{V}=0$ at 4.5 km.

vertical velocity are not available synoptically, Thompson and Collins [3] in computing precipitation rates, used horizontal velocity divergence which can be readily obtained by Bellamy's technique [4] or by other procedures. While Thompson and Collins' method requires divergence computations at several levels for each synoptic case, an approximation of the precipitation resulting from a given value of surface divergence (or vice versa) can be obtained by assuming the vertical variation of horizontal divergence.

Figures 1 and 2 show the precipitation-convergence relationships for two assumed divergence distributions. These relationships were computed under assumptions similar to those used by Fulks, except that instead of his constant (unit) vertical velocity the horizontal convergence was assumed first to be constant with height (fig. 1) and then to have a linear decrease with height to the level of non-divergence (assumed to be at 4.5 km. or approximately 600 mb.) (fig. 2). The latter assumption is believed to be more realistic of atmospheric conditions during periods of cyclonic activity since it closely approximates the model used by Petterssen et al. [5].

Figures 1 and 2 give the rate of precipitation (in./6 hr.) provided that the surface convergence and surface temperature are known. A comparison of the two graphs shows that for the range of surface temperatures used and for a given value of surface convergence, the precipitation rates with a linear decrease of convergence are as much as 55 to 75 percent of the rates with a constant decrease with height. This suggests that the precipitation rate depends largely upon the surface convergence and is not extremely sensitive to the vertical distribution of divergence; thus a linear decrease with height seems to be a reasonable assumption for assessing the magnitude of the relationships. Figure 2 shows that the precipitation rate increases with both increasing surface temperature and increasing convergence.

Given a surface temperature of 60° F. and a surface convergence of 5×10^{-5} sec^{-1}, a 6-hour precipitation of only 0.55 inches is shown by figure 2. Therefore, under the assumptions mentioned, extreme values of surface convergence of about 10^{-3} sec^{-1} must exist in order to obtain heavy rainfall amounts of 2 inches per hour.

For the temperatures used, the greatest 1-km. contribution to the total rainfall rate generally occurred between 3 and 5 km. for a constant convergence, and between 2 and 3 km. for a linear decrease of convergence with height. As a typical example, figure 3 presents histograms of the precipitation rate for 1-km. layers for a surface convergence of 10^{-4} sec^{-1} and a surface temperature of 60° F.

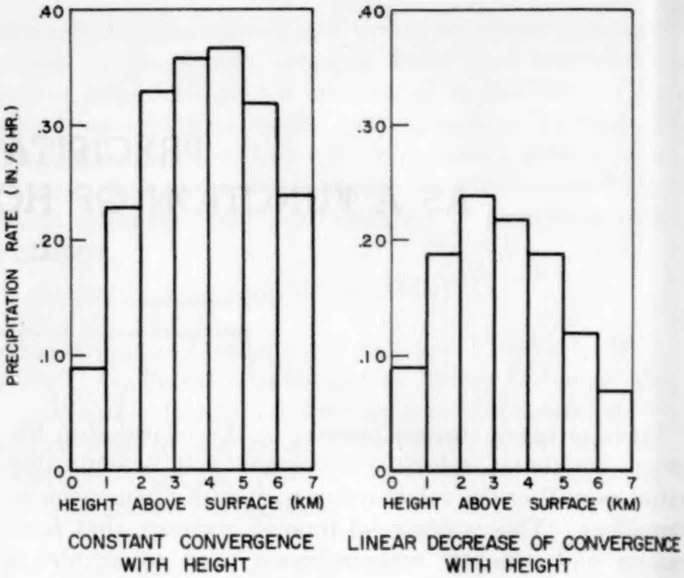

FIGURE 3.—Histograms of precipitation rate for 1-km. layers for a surface convergence of 10^{-4} sec^{-1} and a surface temperature of 60° F.

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WINDS OF THE UPPER TROPOSPHERE AND LOWER STRATOSPHERE OVER THE UNITED STATES

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ABSTRACT

Daily wind data from United States stations for six pressure surfaces (200, 150, 100, 80, 50, 30 mb.) for the period April 1951 through January 1956 are used to study upper winds along the 80th and 120th meridians. At 5-degree intervals along the two meridians, mid-season average wind speeds and prevailing directions have been computed and are compared.

1. INTRODUCTION

The climatology of the upper air, particularly that area above 40,000 feet has been neglected because of the lack of sufficient data. During recent years, with rapid improvements in instrumentation and techniques, an increasing supply of wind data at higher elevations has become available [1]. Although the amount of data has not reached its maximum, sufficient data are now available to establish certain climatological relationships.

Winds over the United States for four mid-seasonal months are compared from latitude 25° N. through 45° N. along longitude 80° W. and from latitude 35° N. through 50° N. along longitude 120° W. This study is confined to the upper troposphere and the lower stratosphere, specifically between the 200-mb. level (about 40,000 feet) and the 30-mb. level (about 80,000 feet). Data used are 1500 GMT rawin observations for a period beginning April 1951 and ending with January 1956. Pilot balloon observations were not used because they are few in number and often considered questionable at these altitudes.

For most of the period, sufficient data were available to obtain climatological averages for single stations. However, this was not possible for the first years of the period for the mid-season months of January, April, and October. Where necessary, data from several nearby stations were combined to arrive at a representative value. The persistence of winds at higher altitudes justifies this procedure.

The 5-year wind speed averages were plotted on maps. Isolines and wind roses were drawn and data for the 5-degree latitudinal intersections of the meridian were interpolated. The arithmetical wind speed averages were then plotted on graphs, and vertical profiles were drawn (figs. 1–8). No subjective interpretations were made in drawing the curves. A very few subjective interpretations were made for prevailing wind directions. In no case was the change more than to the adjacent direction.

In the graphs, prevailing directions are to 16 compass points (i. e., N, NNE, etc.). The first number in parentheses is the percentage of occurrence of the prevailing wind direction. The second number is the percentage of occurrence of the prevailing direction plus the two adjacent directions. (Example: E(50, 75). Prevailing direction east 50 percent of the observations; directions ESE, E, ENE 75 percent of the observations). Small prevailing direction percentages indicate that the directions are fairly well dispersed around the compass.

The phrase "transition zone" is used in the discussion of the graphs to denote the region of minimum wind speed. Decreasing westerly winds in this region usually change rapidly with height to increasing easterlies. This rapid change in the winds is most common during the spring, summer, and fall seasons for southern latitudes and the summer season in northern latitudes.

A good example of the seasonal march of the transition zone is found in comparing two curves which are nearly identical. These are shown by the curves for July 40° N., 80° W. (fig. 5) and October 25° N., 80° W. (fig. 7).

Since this study was based on observed values alone, the possibility of bias toward lower wind speeds in the final results was considered. To assess this effect, synoptic situations for various periods and for stations with abundant data during this period were studied rather thoroughly. The following conclusions bearing on this paper were reached: (1) the layer above the 200-mb. level is above the maximum wind level a large percentage of the time, and therefore decreasing values would be expected with height until the transition zone is reached; (2) high winds would affect the amount of data primarily because the rawinsonde balloon was blown out of range before the 200-mb. level was reached, therefore the levels above the 200-mb. level themselves could not be classified "high-wind" levels for this reason; (3) the abundance of data for the 5-year period would tend to correct the bias toward a reasonable climatological average; (4) the persistence of winds from day to day at these elevations made it possible to detect trends of both lower and higher speeds when values were missing. For these reasons it is believed that the mean values derived can be considered substantially accurate.

The values derived from this study compare closely with those of Kochanski and Wasko [2, 3, 4]. These similarities occur despite different techniques used, and should, therefore, increase confidence in the climatological value of both methods. Similar agreement may be found between these values and geostrophic values from

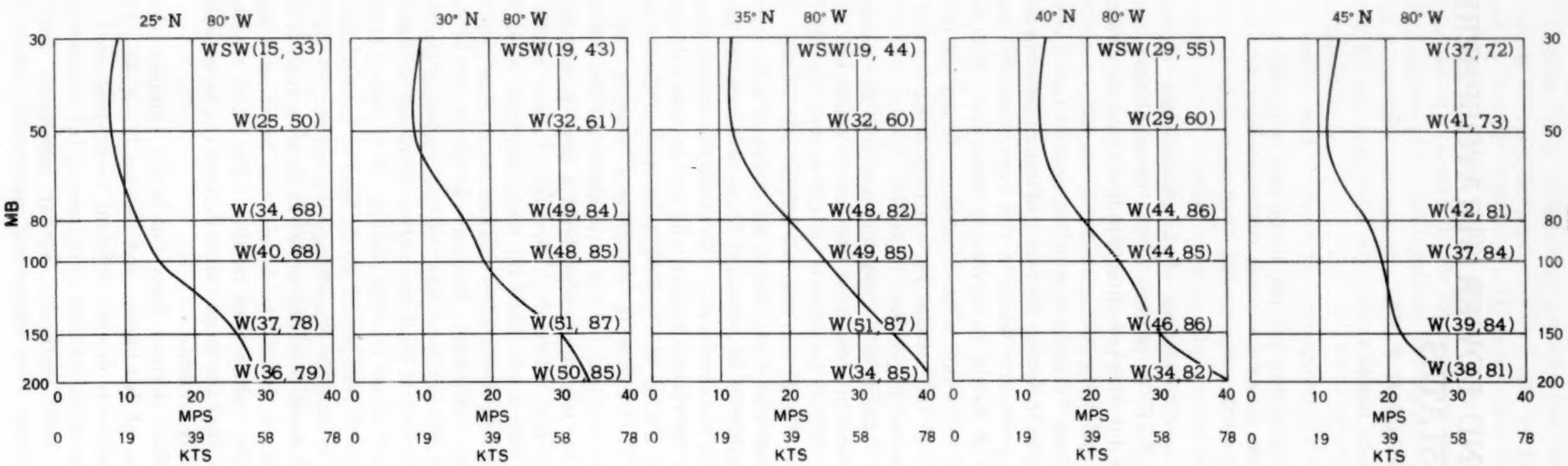

FIGURE 1.—January, 80° W. Average speed and prevailing direction of winds, 200-mb. to 30-mb. levels, from 25° to 45° N. Based on data for 5-year period January 1952–56. Letters at right of each diagram show prevailing direction. First number in parentheses shows percentage of occurrence of prevailing wind direction, second number, percentage of occurrence of the prevailing direction plus the two adjacent directions.

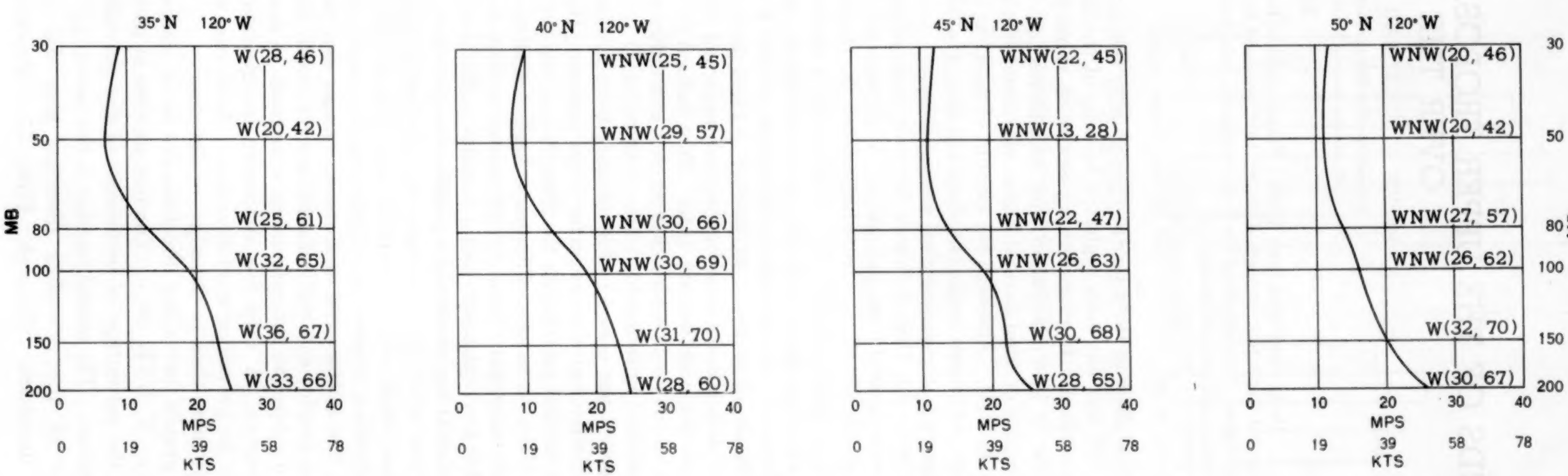

FIGURE 2.—January, 120° W. Average speed and prevailing direction of winds, 200-mb. to 30-mb. levels, from 35° to 50° N. Data for period January 1952–56.

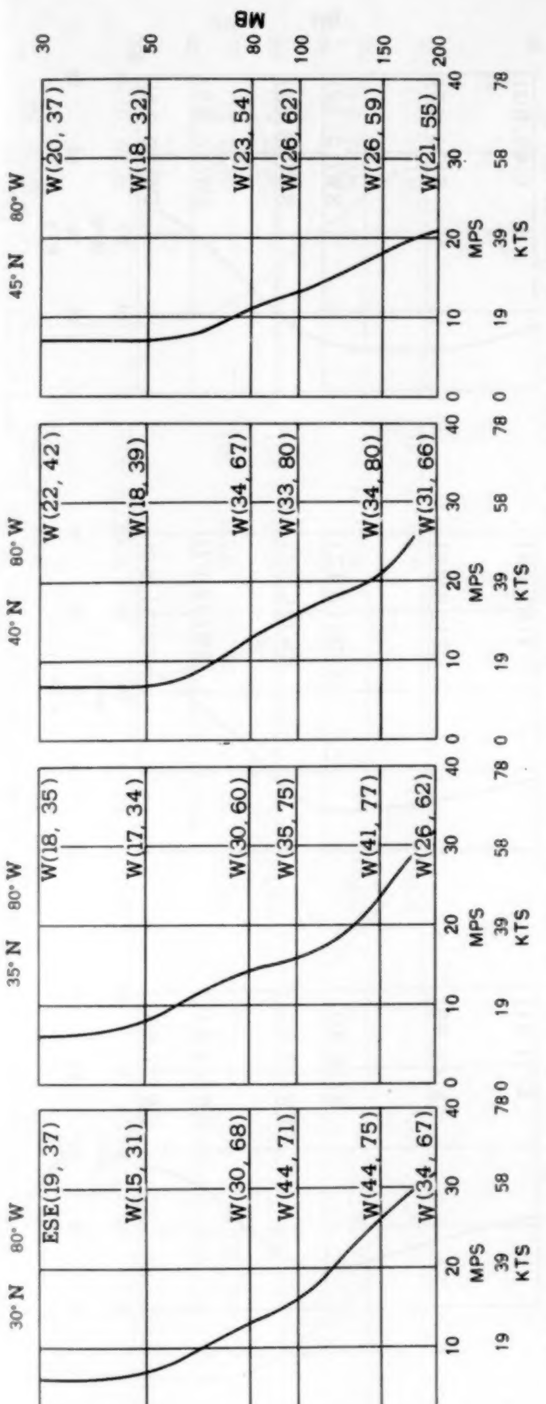

FIGURE 3.—April, 80° W. Average speed and prevailing direction of winds, 200-mb. to 30-mb. levels, from 25° to 45° N. Data for period April 1951–55.

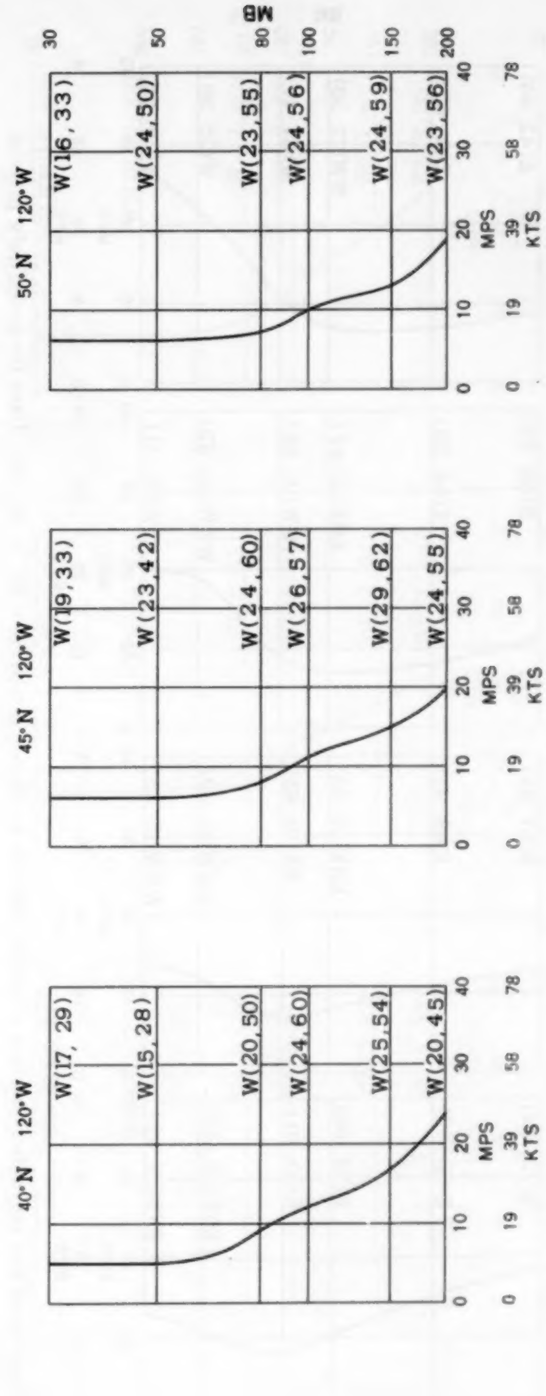

FIGURE 4.—April, 120° W. Average speed and prevailing direction of winds, 200-mb. to 30-mb. levels, from 35° to 50° N. Data for period April 1951–55.

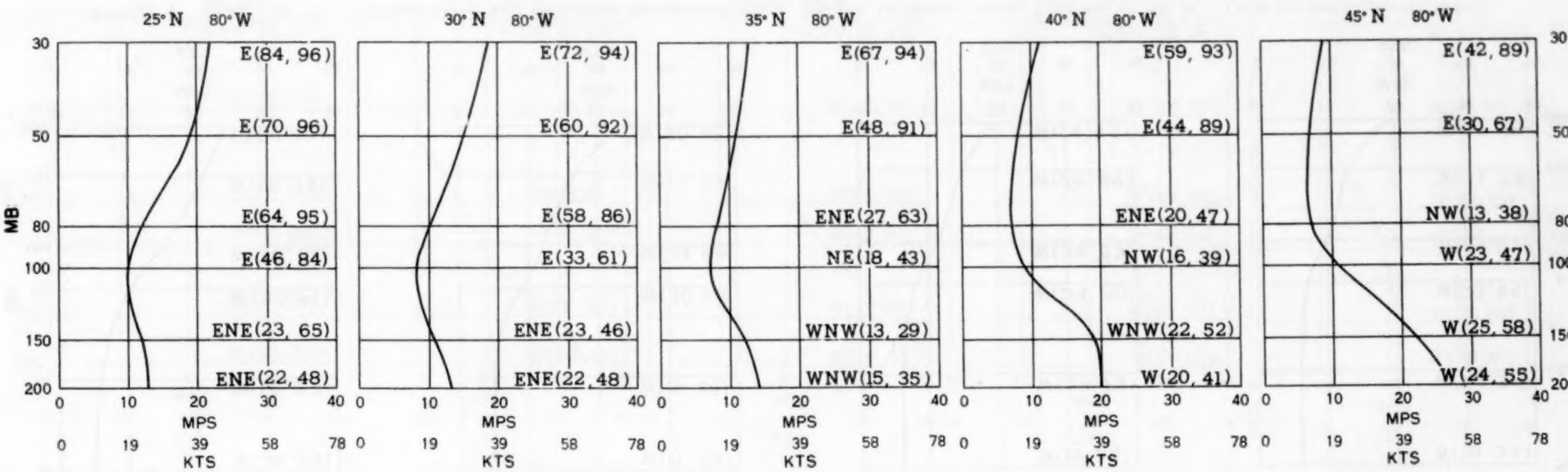

FIGURE 5.—July, 80° W. Average speed and prevailing direction of winds, 200-mb. to 30-mb. levels, from 25° to 45° N. Data for period July 1951–55.

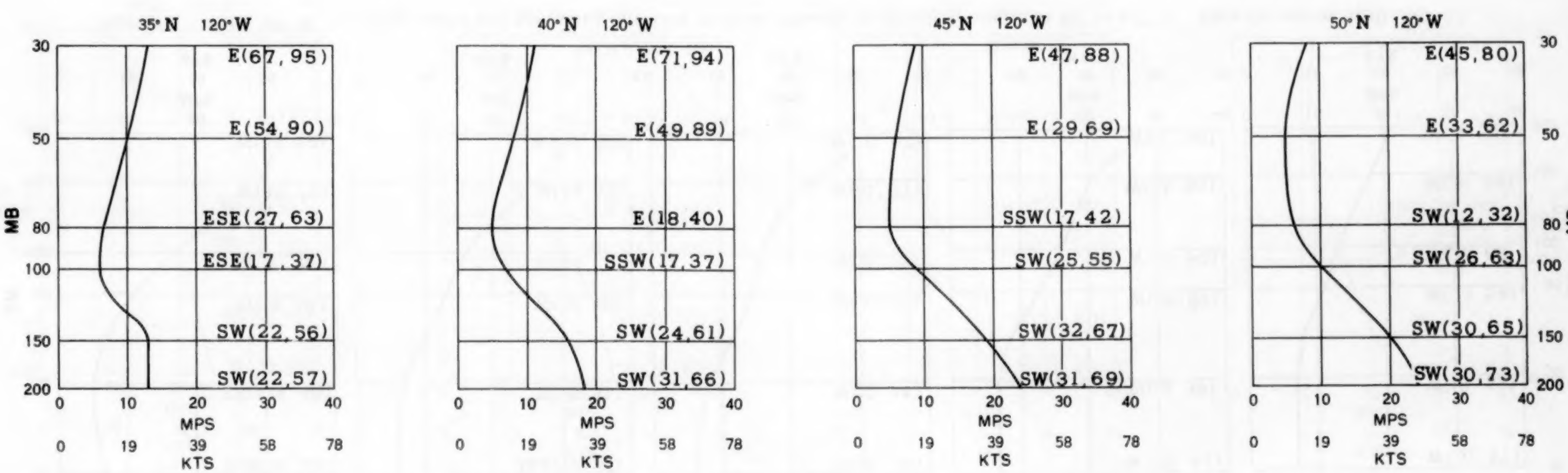

FIGURE 6.—July, 120° W. Average speed and prevailing direction of winds, 200-mb. to 30-mb. levels, from 35° to 50° N. Data for period July 1951–55.

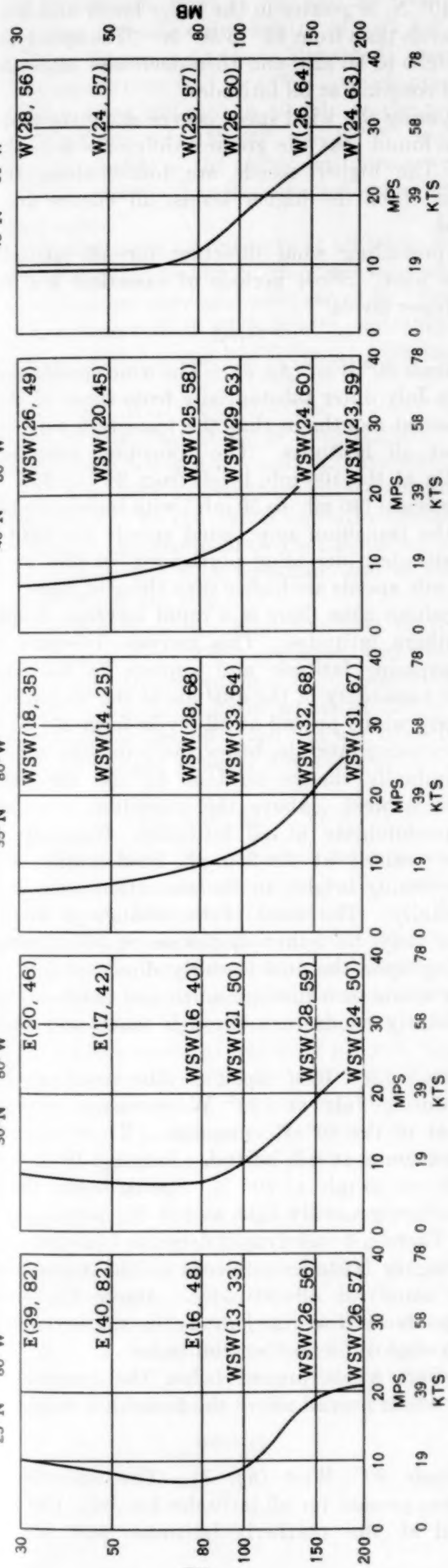

FIGURE 7.—October, 80° W. Average speed and prevailing direction of winds, 200-mb. to 30-mb. levels, from 25° to 45° N. Data for period October 1951–55.

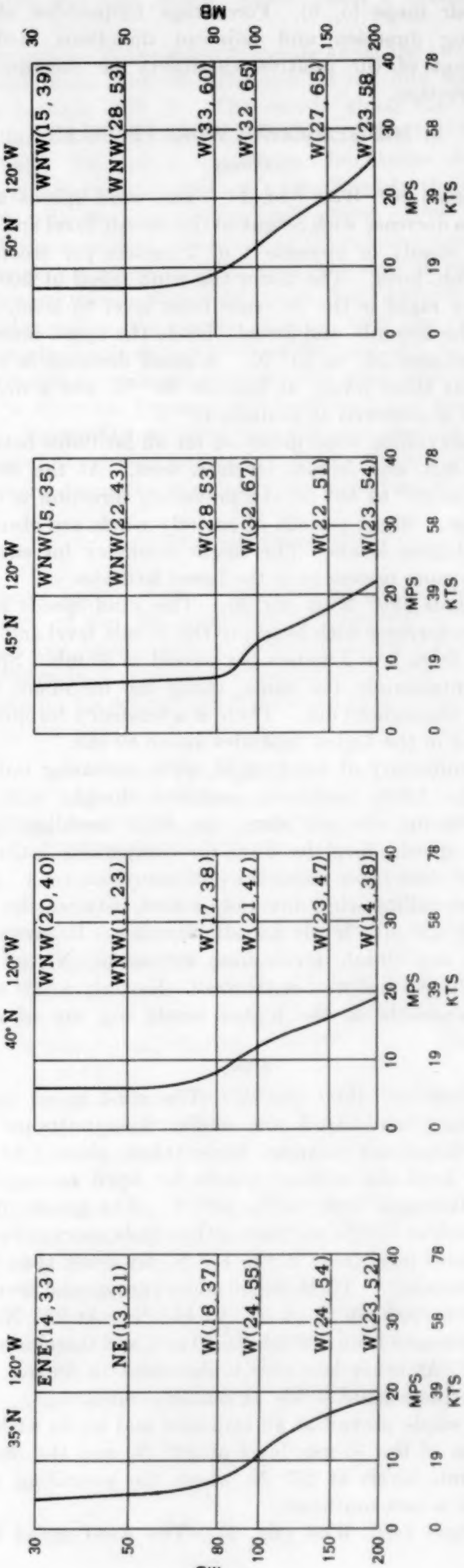

FIGURE 8.—October, 120° W. Average speed and prevailing direction of winds, 200-mb. to 30-mb. levels, from 35° to 50° N. Data for period October 1951–55.

upper air maps [5, 6]. Percentage frequencies of the prevailing direction and adjacent directions facilitate assessment of the relative variability or constancy of wind direction.

2. MID-SEASONAL WIND PROFILES

JANUARY

Longitude 80° West (*fig. 1*).—The wind speeds at all latitudes decrease with height to the 50-mb. level and then become steady or increase 1 or 2 meters per second to the 30-mb. level. The faster the wind speed at 200 mb. the more rapid is the decrease from level to level. Between the 200-mb. and 80-mb. levels the speed increases from latitudes 25° to 35° N. A small decrease in speed occurs, at these levels, at latitude 40° N. and a decided decrease is observed at latitude 45° N.

The prevailing wind direction for all latitudes between the 200-mb. and 50-mb. levels is west. At the 30-mb. level from 25° to 40° N. the prevailing direction is west-southwest. Short periods of easterly winds are observed at the higher levels. This slight tendency for easterly winds is more prevalent in the lower latitudes.

Longitude 120° West (*fig. 2*).—The wind speeds at all latitudes decrease with height to the 50-mb. level and then increase from 1 to 2 meters per second to 30 mb. Speeds are approximately the same, along the meridian, from 200 mb. through 80 mb. There is a tendency for increasing speed in the higher latitudes above 80 mb.

The unformity of wind speed, with increasing latitude along the 120th meridian, contrasts sharply with the more extreme changes along the 80th meridian. The average speeds, level by level for comparable latitudes, are lower than those along the 80th meridian.

The prevailing wind direction is west between the 200-mb. and 150-mb. levels for all latitudes. Between the 100-mb. and 30-mb. levels from 40° to 50° N. the prevailing direction is west-northwest. Easterly winds occur most frequently at the higher levels and are of short duration.

APRIL

Longitude 80° West (*fig. 3*).—The wind speed curves for January and April are similar in appearance but several important changes have taken place. At the 200-mb. level the average speeds for April are approximately the same from 25° to 40° N. The speeds in the lower levels at 25° N. are greater than in January. Speeds in the lower level from 30° to 45° N. are lower than they were in January. There is a 10 meters per second decrease in speed at 200 mb. from 40° to 45° N. At 25° N. the speed decreases from 200 mb. to 50 mb. and then increases slightly. At other latitudes it decreases to 50 mb. and then decreases more slowly or remains constant.

West winds prevail at all latitudes and levels with the exception of the 30-mb. level at 30° N. and the 50-mb. and 30-mb. levels at 25° N. where the prevailing wind direction is east-southeast.

Longitude 120° West (*fig. 4*).—The wind speed from 35° to 40° N. is greater in the lower levels and less in the upper levels than from 45° to 50° N. The speed decreases with height to 80 mb. and then decreases more slowly or remains constant at all latitudes.

Comparing the wind speed curves along the two meridians it is found that the greatest difference is in the lower levels. The higher speeds are found along the 80th meridian. For the higher levels, all curves are nearly identical.

The prevailing wind direction for all latitudes and levels is west. Short periods of easterlies are observed in the upper levels.

JULY

Longitude 80° West (*fig. 5*).—The wind speeds and directions for July differ substantially from those of the other mid-seasonal months in that the transition zone is easily found at all latitudes. The transition zone is lower (generally at the 100-mb. level) from 25° to 35° N., and moves upward (80 mb. to 50 mb.) with increasing latitude. Below the transition zone, wind speeds are light in the lower latitudes, increasing northward, so that at 45° N. the 200-mb. speeds are higher than those of April. Above the transition zone there is a rapid increase in speeds in the southern latitudes. This increase becomes smaller with increasing latitude and appears to be associated with the variability of the altitude of the transition zone.

Easterly winds prevail at all levels from 25° to 30° N. With increasing latitude, below the transition zone, directions gradually change until at 45° N. the prevailing direction is west. Above the transition zone, easterly winds predominate at all latitudes. Generally, winds that are westerly at the 200-mb. level remain westerly, with increasing height, to the transition zone and then turn easterly. The sense of the change to an easterly direction may be either clockwise or counterclockwise depending upon the final westerly direction (i. e., northwesterly winds turn through north and northeast (fig. 5); southwesterly winds turn through south and southwest (fig. 6)).

Longitude 120° West (*fig. 6*).—The trend of changing speeds during July at 120° W. compares very closely with that of the 80° W. meridian. There is a definite transition zone at all latitudes ranging from 100 mb. at 35° N. to 50 mb. at 50° N. Speeds below the transition zone are generally light at 35° N., increasing northward. There is a more rapid decrease from level to level at the higher latitudes. Speeds in the transition zone are the same for all latitudes. Above the transition zone, speeds increase moderately in southern latitudes and only slightly in northern latitudes.

Southwest winds prevail below the transition zone; easterly winds prevail above the transition zone.

OCTOBER

Longitude 80° West (*fig. 7*).—The transition zone which was present for all latitudes for July, has now disappeared at the northerly latitudes, and has moved

upward to the 80-mb. level at 25° and 30° N. Speeds above this zone increase only slightly (2 to 3 meters per second). It is interesting to note the steady increase in the 200-mb. speed from 25° to 45° N., which produces a rapid decrease from 200 mb. to 80 mb. at the northerly latitudes. The curves at 35°, 40°, and 45° N., are similar except that the speeds at the higher latitudes are greater, level for level, and tend to become more uniform with increasing height.

Prevailing directions are westerly at all levels from 35° to 45° N. From 25° to 30° N. they are west-southwest below the transition zone and east above it. Periods of easterlies are observed at all latitudes, but they are of short duration and become less frequent with increasing latitude.

Longitude 120° West (*fig. 8*).—The October trend at 120° W. differs from that at 80° W. only slightly. Speeds in the lower levels increase at a uniform rate with increasing latitude but tend to remain nearly constant above the 50-mb. level. At the 120th meridian speeds in the lower levels average about 20 percent less than those for equal latitudes at the 80th meridian, and in the upper levels about 10 percent less.

Prevailing directions are from the west in the lower levels at all latitudes. They are west-northwest in the higher levels with the exception of slight, perhaps insignificant, predominance of easterly winds at 35° N. Short periods of easterlies are observed but are more frequent, of longer duration, and at lower elevations in the southerly latitudes.

3. CONCLUSION

The most striking dissimilarity between the speed curves for January and curves for the mid-seasonal months of April, July, and October for 80° W. is the consistently higher speeds that occur from 200 mb. through 50 mb. Speeds in January along this longitude average 23 percent higher than in April, 37 percent higher than in July, and 30 percent higher than in October. At 80° W. the mean January speed averages 25 percent higher than for the same points at longitude 120° W. This ratio is greater (about 40 percent) at 35° and 40° N. than for other latitudes. The reason seems to be that the underlying jet stream activity is more persistent across 80° W. at these two latitudes.

Latitudinally, the largest decrease in speed with height at both meridians is at 35° and 40° N. for all seasons. This, of course, takes into consideration the increase in speeds from the 100-mb. to 30-mb. levels during July. Along the 80th meridian the highest 200-mb. speeds are found at 35° N. during January, and the highest 30-mb. speeds are found at 25° N. during July. At 120° W., 200-mb. speeds are approximately the same in January at all latitudes, and the 30-mb. speeds reach a maximum at 35° N. in July.

Comparison of the relative speeds along the two meridians shows the greatest difference for the four seasons is along latitude 35° N. The speeds along the 80° W. meridian are much higher than those along the 120° W. meridian. The curves for the two longitudes shown on the accompanying graphs are approximately the same at 45° N. with the exception of the October curve. It can readily be seen that, disregarding the relative speeds, the curves closely resemble each other in nearly all cases.

The prevailing wind directions are westerly at all latitudes, below the transition zone, with the exception of easterly winds during July at 25° and 30° N. Above the transition zone in summer, the wind seldom varies from a direction between east-northeast and east-southeast. Variability of wind direction is greatest in the region of the transition zone. When no transition zone is present dispersion is greatest in the highest levels.

ACKNOWLEDGMENTS

Sincere appreciation is expressed to Mr. Leslie Smith, Director of the National Weather Records Center, for his aid and encouragement in pursuing this study, and to Mr. Norman L. Canfield, Chief of the Climatic Analysis Section for his editing and technical advice in the preparation of the paper.

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Tables should be typed each on a separate page, with a title provided. They should be numbered consecutively in arabic numerals.

In *equations* conventional symbols in accordance with the American Standards Association Letter Symbols for Meteorology should be used. If equations are written into the manuscript in longhand, dubious-looking symbols should be identified with a penciled note.

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Illustrations. A list of legends for the illustrations should be typed (double spaced) on a separate sheet. Each illustration should be numbered in the margin or on the back outside the image area. To fit into the Review page, illustrations must take a reduction not to exceed 3½″ x 9″ (column size) or 7½″ x 9″ (page size). Map bases should show only political and continental boundaries and latitude and longitude lines, unless data are to be plotted, when station circles will also be needed. Usually the less unnecessary detail in the background the better will be the result from the standpoint of clear reproduction. Line drawings and graphs should also be uncluttered with fine background grids unless the graph demands very close reading. It is not necessary to submit finished drawings, as drafting work can be done at the time the paper is prepared for publication.

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Weather Notes

Many years ago the *Monthly Weather Review* published detailed eye-witness accounts of exceptional storms. These accounts both enrich the meteorologist's knowledge of storms and provide him with particular details that cannot be found elsewhere. Because such information bears directly upon questions the meteorologist must attempt to answer about weather phenomena (for example, the identification of storms as tornadoes), and because the information has potential value in both the research and service programs of the Weather Bureau, publication of eye-witness accounts of exceptional storms and other meteorological phenomena was resumed in the April 1955 issue. They appear from time to time under the heading "Weather Notes."

Contributions to these "Notes" are invited from readers of the Review. There is no limitation placed on length of description but it is expected that most will be short accounts. Any weather peculiarities, whether storms or other phenomena, are acceptable subject matter. Material should be addressed to Editor, Monthly Weather Review, U. S. Weather Bureau, Washington 25, D. C.

THE WEATHER AND CIRCULATION OF JANUARY 1957 [1]

A Month with a Persistent Block in the Gulf of Alaska

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1. SELECTED ASPECTS OF THE MONTHLY MEAN CIRCULATION

GULF OF ALASKA BLOCKING

Blocking conditions in the Gulf of Alaska region prevailed throughout January 1957. The consequences of that aberration will be emphasized, but first it will be shown how this tenacious feature fitted into the general circulation.

Figure 1 is the 700-mb. 30-day mean chart for January 1957. The hemispheric circulation consisted of three full-latitude troughs located along the east coasts of Asia and North America and near the Ural Mountains. The pattern would have been rather symmetrical had there been a fourth full-latitude trough in the eastern Pacific Ocean. Instead, the flow in that area was distorted by two low-latitude troughs with a short wavelength, separated by a ridge of great amplitude.

The southern portion of the eastern Pacific ridge was located in an area in which a ridge occurs on the normal map for January [13]. However, that portion of the ridge in the Gulf of Alaska was highly anomalous. On the normal 700-mb. chart for January, cyclonic curvature characterizes the latter region; but in January 1957 the curvature was markedly anticyclonic, and the contour heights were far above normal.

The dotted lines in figure 1 represent the height departures from normal (hereinafter called DN). The large magnitude (+720 ft.) and extent of the height DN near Alaska overshadowed all other centers in the Northern Hemisphere. This DN center apparently started in the eastern Pacific as a small positive height anomaly early in the month. Meanwhile, the Siberian block of December 1956 investigated by Green [2] relaxed, and its associated positive height DN progressed to eastern Siberia. Thereafter, at least a portion of this DN appears to have amalgamated with and reinforced the mushrooming anomaly of the eastern Pacific.

Another indication of the anomalous flow in the eastern Pacific is given by the monthly mean isotach chart (fig. 2). Not only were 700-mb. wind speeds in this area very weak, but also the belt of maximum westerlies was split into two branches. One axis of the mean jet stream entered North America in Baja California, while the other crossed the Arctic Ocean and Beaufort Sea into northwestern Canada. The great departure of this wind speed distribution from the January normal and from the pattern of December 1956 (see fig. 3A of [2]) was a direct consequence of the persistent blocking in the Gulf of Alaska.

The mean sea level chart for January and its anomalous pressure field (fig. 3) also reflects the blocking. On the January normal sea level map [13] high pressure in the eastern Pacific is confined to the area southward from 40° N., while the region north of 40° N. is occupied by a lobe of the Aleutian Low. This month, in contrast, the eastern Pacific was covered by an extensive meridional anticyclone, and sea level pressures in the Gulf of Alaska were as much as 21 mb. above normal.

KONA STORM

The broad cyclonic sweep over the western Pacific (fig. 1) advected relatively cold air into subtropical latitudes of the central Pacific. The resulting low-latitude trough west of Hawaii was suggestive of Kona Low development. One such storm was observed in the latter half of January, and its evolution from an occluding wave paralleled that described by Simpson [11].

Thirty-day mean DN charts at 700-mb. (fig. 1) and sea level (fig. 3) show only small below normal values in the central Pacific in an absolute sense (−110 ft. and −5 mb.). On the other hand, those anomalies were appreciable when one considers the low variability of sea level pressures and 700-mb. heights in subtropical areas [4].

Copious rainfall over the Hawaiian Islands resulted from the sudden development of the Kona vortex. Heavy rains continued as the storm stagnated northwest of the Hawaiian chain. 14.19 inches of rain fell at Honolulu during January 1957, or about 60 percent of its mean annual rainfall. Other amounts ranged from 3.03 inches on leeward Maui to 18.17 inches on windward Kauai.

Qualitatively, the Kona Low was apparently effective in the transporting of tropical air into high latitudes. As cold air from Asia was transported into the west side of

[1] See Charts I–XVII following p. 36 for analyzed climatological data for the month.

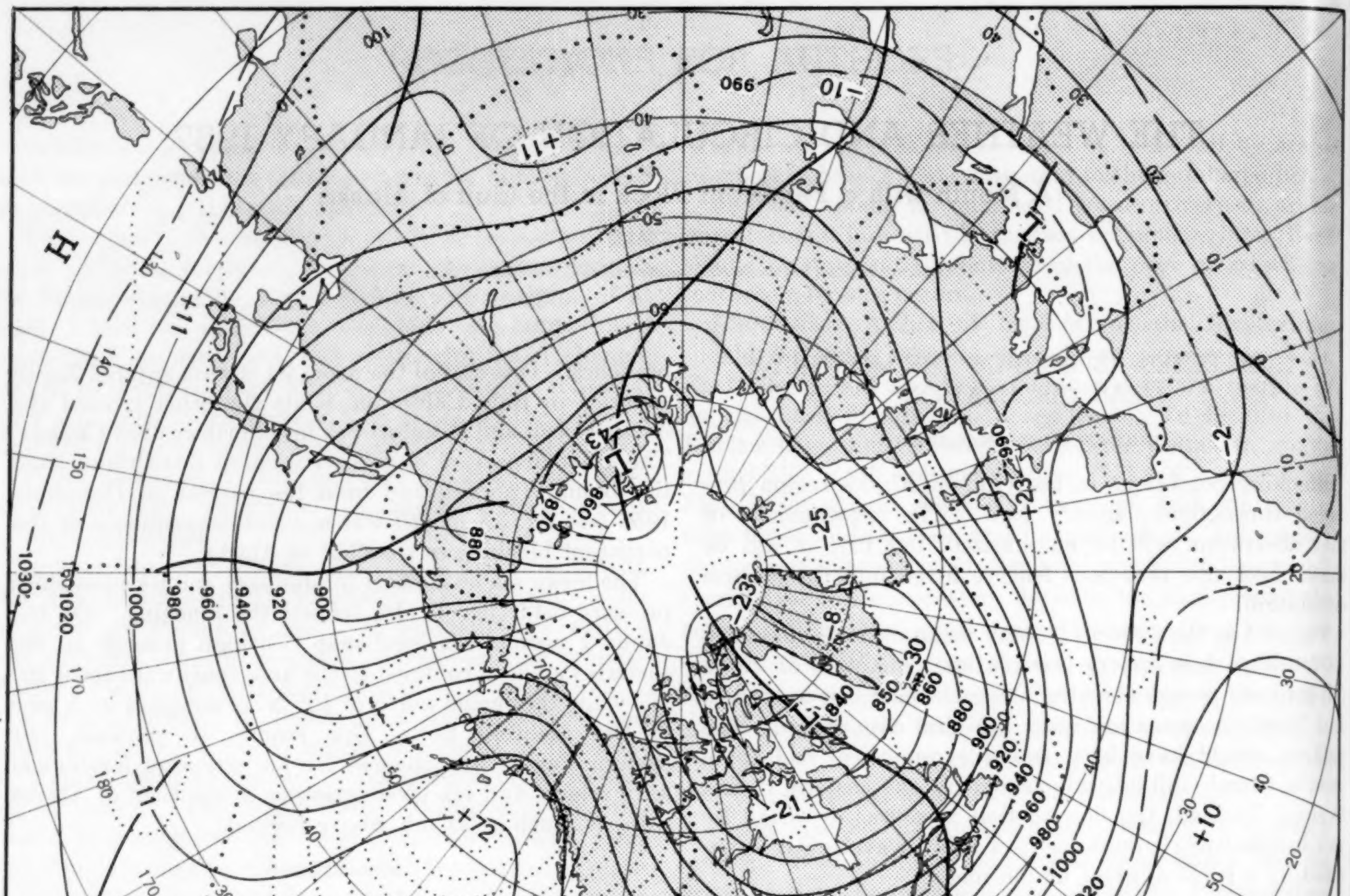

FIGURE 1.—Mean 700-mb. contours and height departures from normal (both in tens of feet) for January 1957. The most anomalous trough-ridge system was located in the eastern Pacific.

the Kona trough, the warm air stream on its east side was maintained, and the ridge over Alaska continued its growth. The circulation over North America was apparently influenced by this Alaskan block, as described below.

NORTH AMERICAN FEATURES

In some respects the circulation over North America (fig. 1) was similar to the normal January 700-mb. circulation. Principal differences in January 1957 include a westward extension of the Bermuda High into the Gulf of Mexico, a westward displacement of the California trough, and a northwesterly flow from Alaska to California instead of a moderate westerly current.

Those departures from the normal flow resulted in DN centers which were significant but were generally small in magnitude. The DN flow [3] around the −120-ft. center near California resulted in below normal thicknesses in the Northwest but greater than normal values in the Southwest (fig. 4). The +140-ft. DN center in the western Gulf of Mexico assisted the flow of warm air into the confluent zone in the Southeast. The −210-ft. center over Hudson Bay and the trough in the anomaly

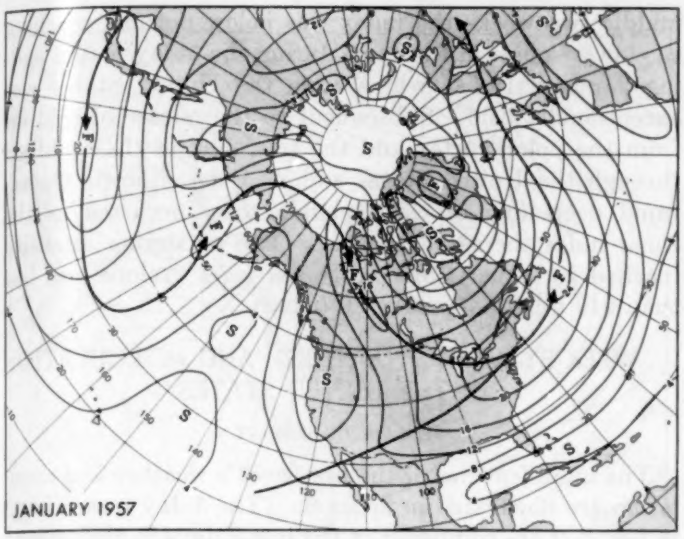

FIGURE 2.—700-mb. mean isotachs in meters per second for January 1957. Solid arrows indicate positions of mean 700-mb. jet axes. Confluence between cold Canadian air and relatively warm maritime air was associated with fast westerlies over eastern United States and over the Atlantic Ocean.

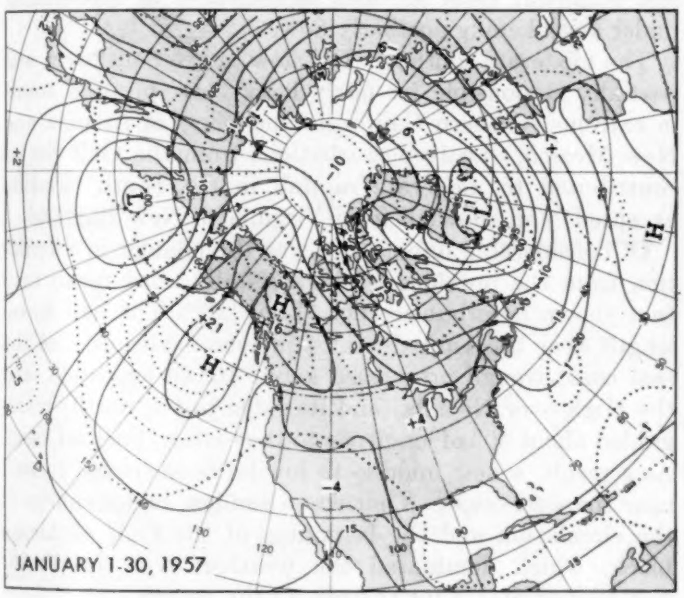

FIGURE 3.—Mean sea level isobars and pressure departures from normal (in millibars) for January 1957. The strong flow from Canada suggests successive cold outbreaks over the United States.

pattern to its southwest indicate the abnormal 700-mb. flow which recurrently deployed Arctic air into the United States. The axis of this current is well delineated by the jet stream over western Canada in figure 2. As a result mean thickness values in the layer from 1,000 to 700 mb. averaged below normal over most of Canada and the United States (fig. 4).

Sea level isobars and DN values (fig. 3) over North America show the predominance of the strong High near the Yukon and the ridge southeastward to the South

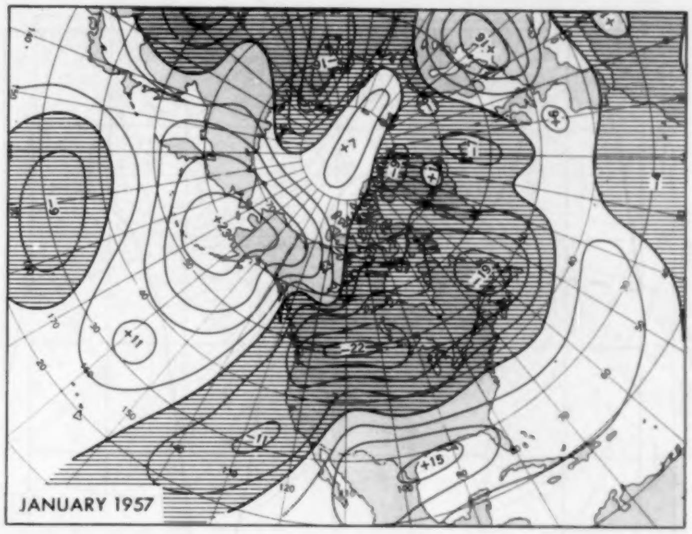

FIGURE 4.—Mean thickness departures from normal (1000 to 700-mb.) for January 1957 (in tens of feet). Below normal thicknesses (shaded areas) occurred over northern and central United States, with above normal values in the South.

Atlantic States. This pattern would lead one to anticipate the relatively high frequency of migratory anticyclones over the United States and western Canada shown by Chart IX. The strong northerly surface flow observed over central Canada was concomitant with the combination of the Alaskan block (described above) and the Icelandic Low (considered below).

THE ICELANDIC LOW

The intensity of the Icelandic Low, another interesting feature of the general circulation for January, is indicated by the dotted anomalies of figures 1 and 3, which show that departures from normal for the month averaged −300 ft. at 700 mb. and −11 mb. at sea level. To its south a strong band of temperate westerlies extended from the central United States to the central Atlantic, with mean speeds over 24 m. p. s. at the 700-mb. level (fig. 2). This was associated with confluence in the east-central United States as the northwesterly flow from Canada met the southwesterly flow from the Pacific Ocean. Note the juncture of the two branches of the jet stream in figure 2 and the strong thermal gradient in the United States and in the western Atlantic (fig. 4). This was conducive to the frequent genesis of cyclones, whose intensity and daily tracks are given in Chart X. The impetus of the strong westerlies helped drive successive storms into the climatologically favored area near Iceland, where they underwent strong deepening.

Another consequence of the deep Icelandic Low was the warming which dominated Europe during January, as indicated by above normal thicknesses in figure 4. The 700-mb. ridge in that area, together with the strong westerlies over eastern United States and the western Atlantic Ocean, led to continued intrusions of mild, maritime air which produced above normal temperatures over much of Europe.

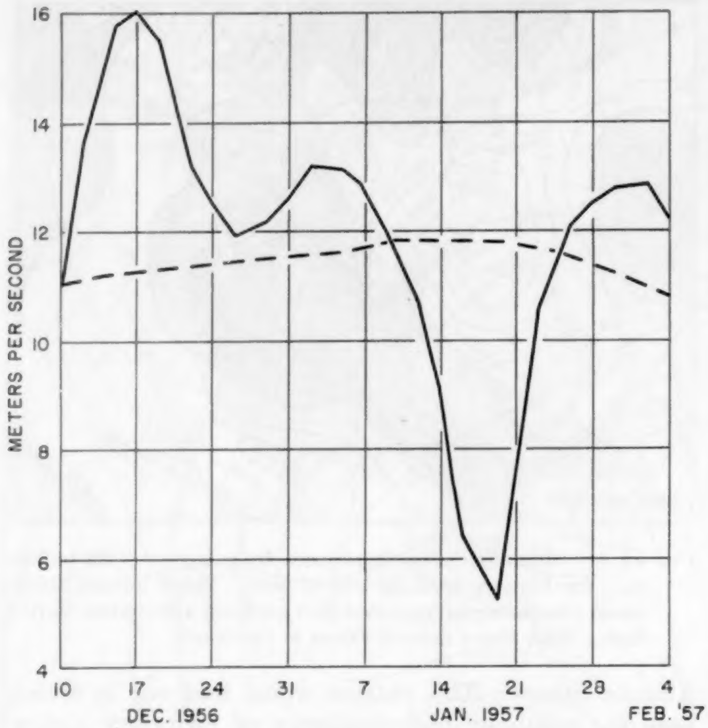

FIGURE 5.—Time variation of the temperate-latitude 5-day mean zonal index (average strength in meters per second of the 700-mb. zonal westerlies between 35° and 55° N. at longitudes 5° W. westward to 175° E.), December 10, 1956, to February 4, 1957, plotted at the end of each period. Dashed line indicates normal index values. This is a fine example of an index cycle for the Western Hemisphere. The precipitous fall of index by January 19 was accompanied by strong meridional flow on either side of the Alaskan block.

AN INDEX CYCLE

Figure 5 is a time-latitude diagram of the speed of the mid-latitude westerlies over the Western Hemisphere from mid-December 1956 through January 1957. This zonal index reached a maximum value in mid-November 1956 [1], which was the beginning of an index cycle during December described by Green [2]. The very high index of 16 m. p. s. in mid-December marked the onset of another index cycle of even greater magnitude.

The January index cycle differed from most of the primary index cycles observed by Namias [8, 9] in that the latter usually occurred in February or March and were accompanied by a clear cut southward displacement of the westerlies. The magnitude of this index cycle is shown by the fact that the zonal index changed from about 5 m. p. s. above normal in mid-December to more than 6 m. p. s. below normal in mid-January. Of additional interest is a comparison of United States temperatures for the two months. In December 1956 roughly three-fourths of the United States was above normal; in January 1957 about the same portion of the United States was below normal.

During the index cycle of January the zonal index was above normal in the first and last weeks. During the middle two weeks the index was below normal, reaching the lowest point of the cycle during the 5-day period ending January 19, at which time the United States was exceptionally cold. Subsequent to the release of cold air from the polar vortex and the transport of that cold air through the United States and into the Atlantic Ocean, rapid deepening of the Icelandic Low occurred as the zonal index increased sharply. The maximum intensity reached by a particular daily sea level cyclone was less than 940 mb. on January 26 (Chart X).

2. WEEK-BY-WEEK WEATHER AND CIRCULATION IN THE UNITED STATES

WEEK ENDING JANUARY 7

The main features of the first week's weather and circulation are illustrated in figure 6. (The 5-day mean charts in figs. 6–9 are composed of the last 5 days in each week.) Generally high index was accompanied by mild temperatures and little precipitation over much of the United States. But there were some exceptions. Below normal temperatures in the Far West were consistent with the cold trough in the area. The East and Northeast were still cold, but those sections appeared to be moderating under a weakening northerly flow.

The moderate southerly DN flow in the Southwest was partially responsible for fairly heavy precipitation totals in extreme southern California and parts of Arizona and New Mexico. Daily perturbations from the Gulf States contributed to moderate rainfall in the South (Florida excepted) and snowfall from Virginia to New England.

Of considerable importance was the change in circulation from the previous week's 700-mb. 5-day mean map (not shown here but see fig. 5D of [2]). The half-wavelength over the United States increased abruptly as the east coast trough progressed about 10° of longitude, and the High over Nevada (and its ridge to the north) retrograded about 30° of longitude to the eastern Pacific Ocean. As a result, a new middle- to low-latitude trough formed near the west coast. That was a sudden, major change in the circulation and the beginning of the Gulf of Alaska block, which dominated the weather over the Pacific and United States for the rest of the month.

The zonal index of 12.9 m. p. s. (fig. 5) was slightly above normal, but the downward trend was in progress.

WEEK ENDING JANUARY 14

The 700-mb. 5-day mean chart corresponding to the second week of January (fig. 7) exhibits a general picture of three full-latitude troughs around the Northern Hemisphere with one middle- to low-latitude trough off the United States west coast and several low-latitude troughs in other parts of the hemisphere. Most of these troughs were displaced westward from their positions of the previous week.

Of particular note were several large-scale changes. Blocking appeared over the eastern Atlantic, as shown by the closed High off Britain with 700-mb. heights 900 ft.

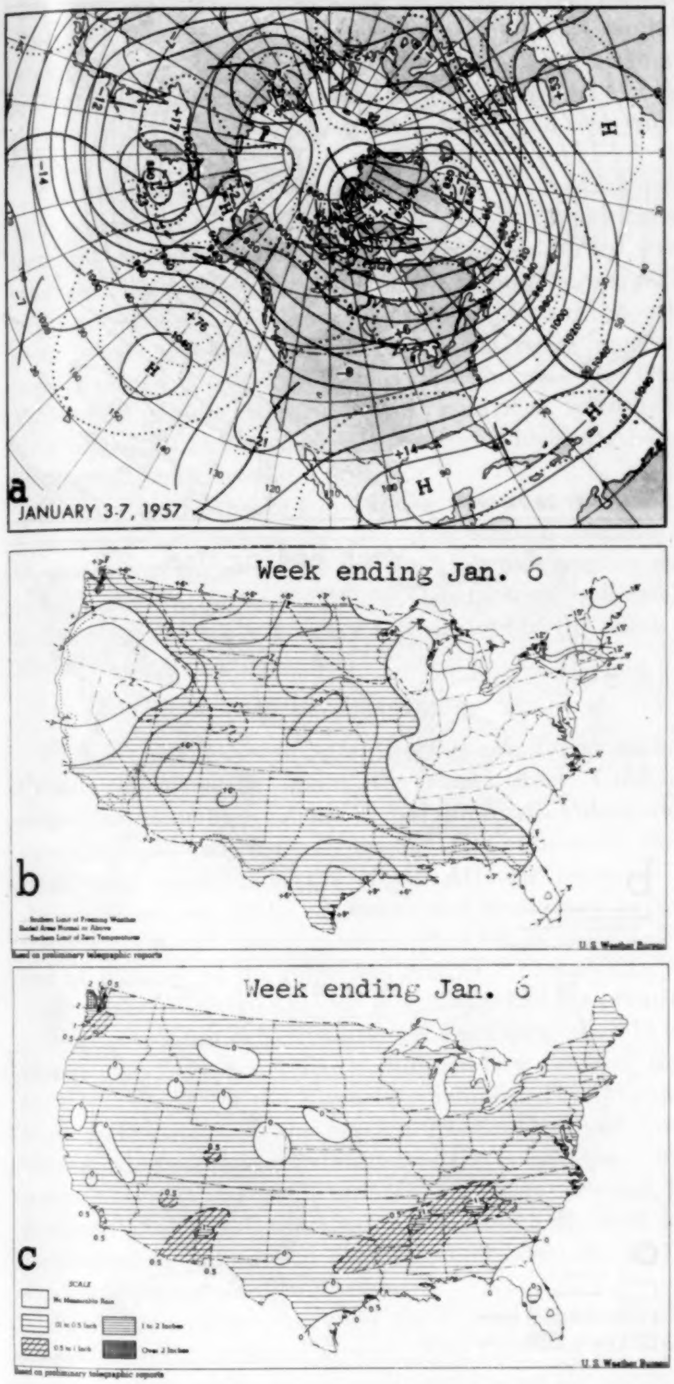

FIGURE 6.—(A) 5-day mean 700-mb. heights and departures from normal, (B) surface temperature departure from normal and (C) total precipitation, for first week in January 1957. Outstanding features of circulation pattern (A) included the mid-Pacific trough, the eastern Pacific ridge and trough, and the broad cyclonic sweep from eastern United States to Europe. As shown in (B), cold air from Canada had not yet replaced Pacific and mild Gulf air over the central half of the United States. Rain areas in (C) resulted from penetration of weak cyclones.

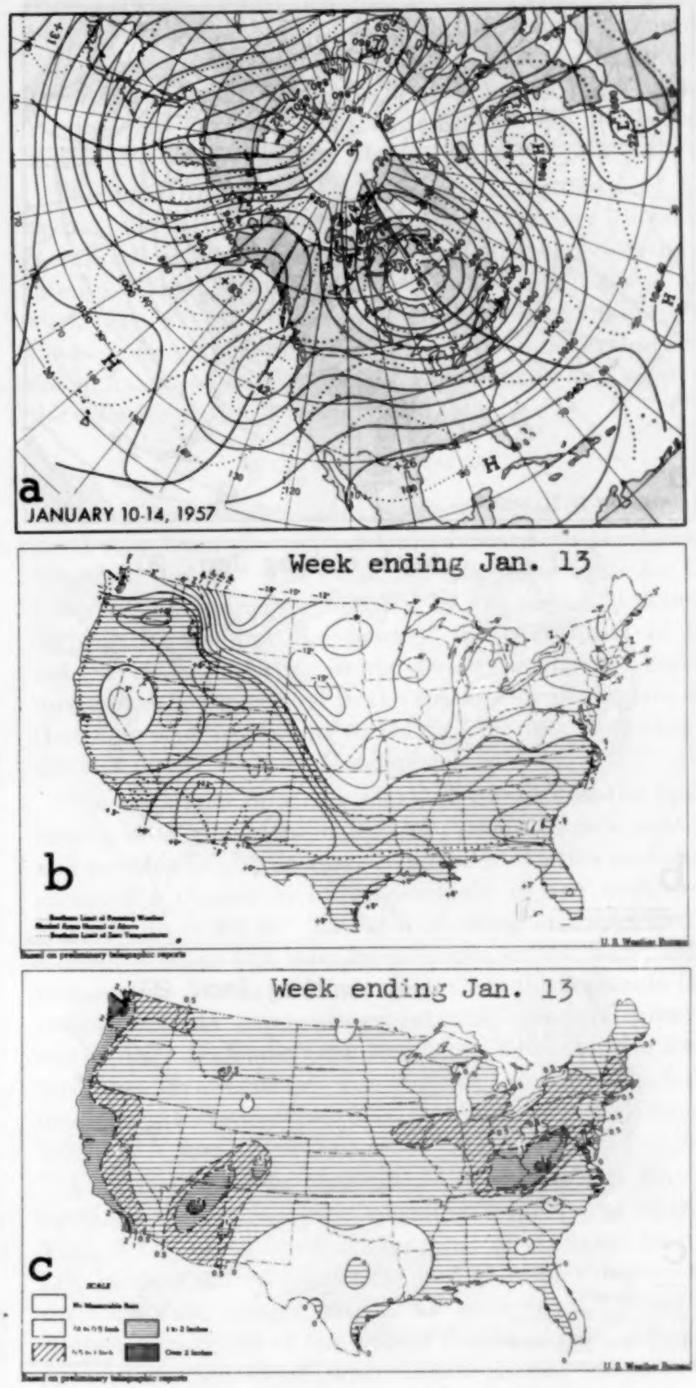

FIGURE 7.—Circulation and weather of second week of January 1957. A general intensification at the 700-mb. level showed up as increased height anomaly gradients over North America. (A) The well-established blocking in the Gulf of Alaska was instrumental in the eastern Pacific deepening which, in turn, flooded the West with mild air (B) and brought moderate to heavy precipitation along the west coast (C). Note cold invasion in North and Northeast which followed a snow-producing cyclone spawned in the middle Mississippi Valley.

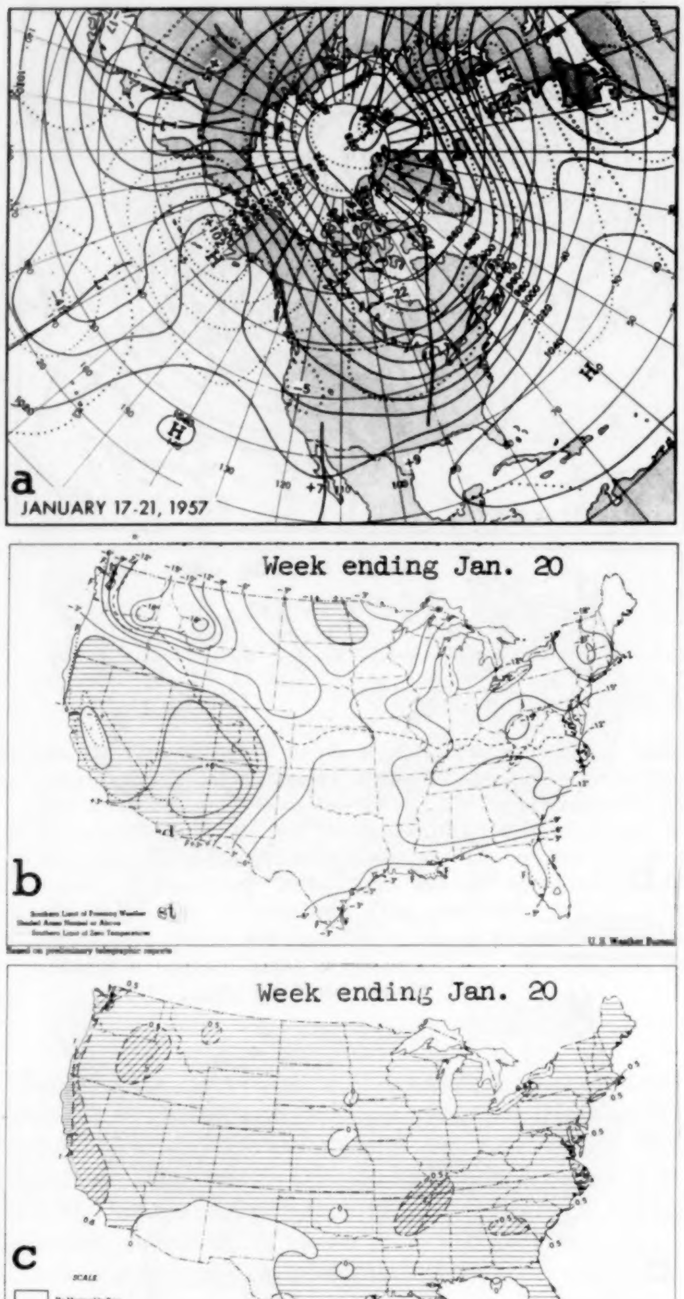

FIGURE 8.—Circulation and weather of third week of January 1957. Retrogression of the east coast trough and the Gulf of Alaska block proceeded as the west coast trough filled. Contours and height anomalies (A) show the extent and magnitude of the Kona Low as it became a major feature of the Pacific circulation. The southward and eastward progress of the polar air across the United States (B) and the generally light precipitation (C) were indicative of the lack of DN flow from maritime moisture sources.

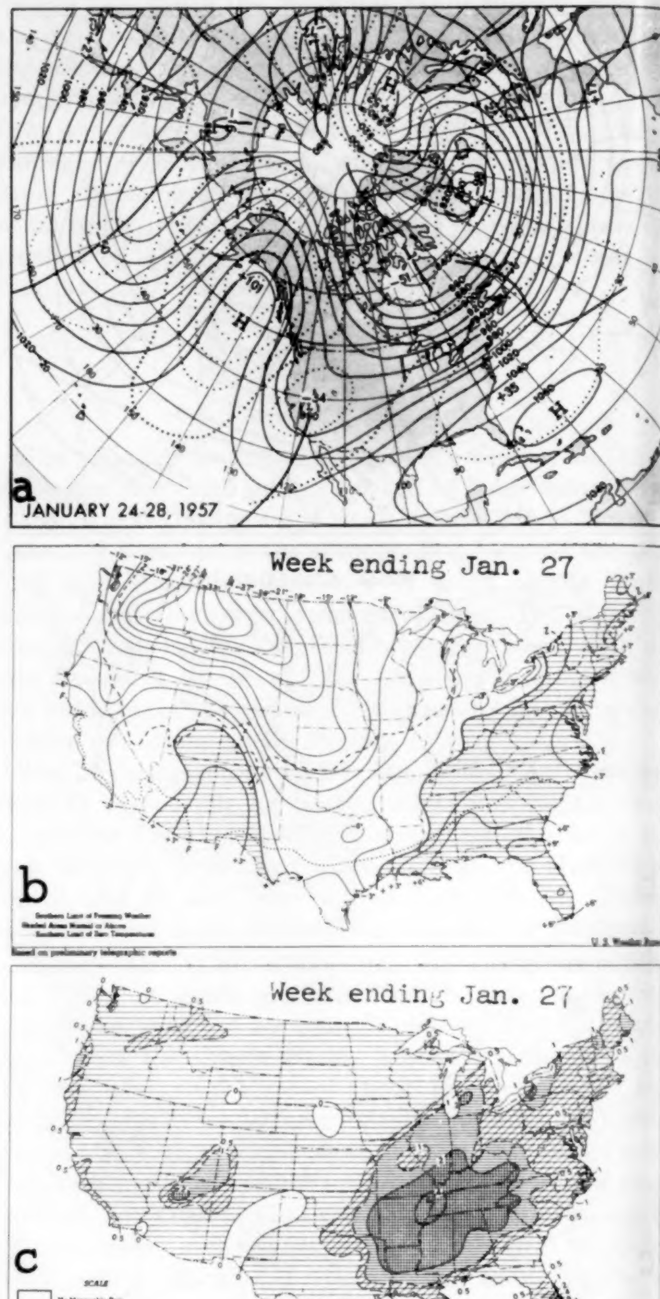

FIGURE 9.—Circulation and weather of the fourth week of January 1957. Mid-tropospheric circulation (A) was marked by progression and intensification of major features. The north-south rearrangement of the Gulf of Alaska ridge was conducive to redevelopment of the California trough. The increased strength of the Bermuda High resulted in a strong anomalous 700-mb. flow from the Gulf of Mexico. The warming (B) and the increased precipitation (C) in the eastern United States were consistent with the increased DN flow from the Gulf of Mexico. The intense cold outbreak over most of the West and Midwest caused all time low record temperatures at several stations. (See table 1.)

above normal. This occurred concurrently with a marked westward displacement of the Icelandic Low. Simultaneously, the block in the Gulf of Alaska became more pronounced. The result was a strong advection of cold air into the United States, where intense cold was widespread.

The intensification of the west coast trough was followed by moderate to heavy rainfall in the Pacific Coast States. Drought conditions of several weeks in California were relieved. As the southerly DN flow became stronger, it effectively transported more maritime air into the Southwest, where Arizona and nearby areas again received heavy rains. Considerable precipitation in the Ohio Valley and Middle Atlantic States resulted as warm Gulf air released its moisture in disturbances which originated in the west coast trough.

During this week the zonal index was 9 m. p. s., some 3 m. p. s. below normal (fig. 5). A continued decrease in the index was suggested by the fact that blocking regimes in both the Pacific and Atlantic Oceans were well-established, with extensive positive DN centers to the north of sizeable negative DN centers.

WEEK ENDING JANUARY 21

Changes in the North Atlantic Ocean and over eastern Canada occurred at about the same time. Cold air surged from northern Siberia across the North Pole toward Greenland, as shown by figure 8. The apparently well-established blocking in the North Atlantic retreated to the southeast, as Arctic air continued southward beyond Iceland. 700-mb. 5-day mean heights fell as much as 800 feet at Iceland, as the ridge was eroded. Meanwhile, the vortex over northern Quebec essentially lost its identity.

Another prominent circulation change took place in the eastern Pacific Ocean. The meridional flow resulting from the development of the Kona Low reinforced the Alaskan block. The ridge in the eastern Pacific Ocean at lower latitudes became more extensive as the ridge over southwestern United States disappeared. As that occurred, the northern portion of the west coast trough sheared and progressed to the Great Lakes area; the southern part of the trough progressed more slowly.

Extensive cold weather over the United States resulted from the evolution noted above. The East and the South became much colder, as is seen by comparing the temperature anomalies in figures 7 and 8, and several new low records were established (table 1). A general warming in the Northern Plains States followed a surge of warm air from northern Alaska which could conceivably be traced back to the central Pacific Ocean (see DN flow in fig. 8). A detailed account of the activity associated with the rapid deepening off the west coast is given by Norton and Kulawiec [10] in an adjoining article in this issue.

Precipitation decreased considerably during the third week. Areas of prolonged drought in the central and southern Plains States received no more than 0.05 inch of rain. In the Far Southwest rains diminished as the Pacific trough moved inland. Westerly winds aloft and a negligible DN flow discouraged further sizeable amounts of precipitation. The rain area over the Ohio Valley also diminished as cold air drove southward to the Gulf of Mexico. At the same time, the Bermuda High retreated eastward from the Gulf of Mexico.

The zonal index (fig. 5) reached its minimum of 5.2 m. p. s. during the 5-day period ending January 19, when meridional flow over the Western Hemisphere was most intense. The 700-mb. mean for the last five days of the week (Jan. 17–21) represents a zonal index of 7.9 m. p. s., the beginning of the second phase of the index cycle. The rise in index can be accounted for principally as a result of the collapse of the Atlantic block.

WEEK ENDING JANUARY 28

The return of higher index is substantiated by the strong zonal flow from the central United States to the United Kingdom (fig. 9). The mean 700-mb. zonal index for the 5-day period ending on January 28 was about 10 percent higher than normal and marked the completion of the index cycle which began in mid-December (fig. 5). Strong meridional flow persisted in the eastern Pacific Ocean, but that flow was insufficient to balance the fast westerlies in the rest of the Western Hemisphere.

The beginning of a new blocking impulse in the Spitzbergen area is evidenced by the closed 700-mb. contour and positive height anomaly in figure 9. In this area there occurred a change in height anomaly in one week from −800 ft. to +500 ft. This new blocking first appeared as a small positive DN over Spitzbergen on the 5-day mean map ending January 26 (not shown), as the Icelandic Low intensified. At its maximum intensity sea level pressure of the daily Icelandic Low was below 940 mb., the 5-day mean sea level pressure was 965 mb., the 700-mb. 5-day mean height was less than 8000 feet, and the 5-day 700-mb. height DN was −980 ft.

A general cooling took place from Hudson Bay to southern California, with warming from Texas to New York. The north-south realignment of the large positive DN in the Gulf of Alaska favored the redevelopment of the California trough, as cold air once again flooded the western two-thirds of the United States (fig. 9), excepting parts of the Southwest, where above normal temperatures prevailed. Record-breaking low temperatures were reported in parts of Montana, Washington, and Oregon (table 1).

With warming in the East came moderate to heavy precipitation from eastern Texas to New England. Some local flooding occurred in Palm Beach and Martin counties of southern Florida, as amounts from 3 to 15 inches were reported. Increasing rainfall in the southern Appalachian area initiated severe flooding which followed heavy rains from January 27–30. Displacement of the warm air by colder air was responsible for several tornadoes reported in Oklahoma, Tennessee, and Louisiana.

TABLE 1.—*New temperature, precipitation, and windspeed records established during January 1957*

Date	Station	Value	Remarks
	TEMPERATURE		
		(° F.)	
15	Booneville, N. Y.	−55	All time low for New York State.
15	Burlington, Vt.	−29.6	All time low.
15	Rochester, N. Y.	−16	New January low.
15	Syracuse, N. Y.	−24	New January low.
15	Worcester, Mass.	−19	All time low.
18	Baltimore, Md.	−4	All time low at Friendship Airport.
18	Hartford, Conn.	−17	New January low at Bradley Field.
26	Missoula, Mont.	−33	All time low.
26	Olympia, Wash.	0	New January low.
27	Burns, Oreg.	−25	All time low.
27	Pendleton, Oreg.	−22	All time low.
31	Houston, Tex.	83	New January high.
	PRECIPITATION		
		(inches)	
8, 9	Detroit, Mich.	8.9	Greatest 24-hour snowfall at City Airport.
23	Pendleton, Oreg.	17	Greatest all time depth of snow on ground.
Jan.	Apalachicola, Fla.	.04	Lowest January rainfall.
Jan.	Grand Junction, Colo.	33.7	Greatest snowfall any month.
Jan.	Great Falls, Mont.	1.8	Greatest January precipitation.
Jan.	Miami, Fla. (CO)	.08	Lowest January rainfall since 1911.
Jan.	Tallahassee, Fla.	.21	Lowest January rainfall.
	WIND		
		(m.p.h.)	
8	Prescott, Ariz.	47	Highest for January at Municipal Airport.
19	Lincoln, Nebr.	58	Highest for any winter month.

3. COMPARISON WITH OTHER JANUARYS

Chart I–B indicates that monthly mean temperatures in the United States during January 1957 averaged above normal in the Southeast and Southwest, but below normal in the remainder of the nation, with maximum departures (−12° F.) in Montana. Precipitation (Charts II and III) was greater than normal in the Southwest and in the Tennessee Valley region. Subnormal amounts were observed in the Northeast, Northwest, Great Plains, and along the coast of the Gulf of Mexico. The relation between these weather anomalies and the pattern of the general circulation has previously been discussed. Of greatest importance was the strong northerly flow over Canada and the northern United States between the blocking ridge in the Gulf of Alaska and the deep Icelandic Low. Also noteworthy were the deeper than normal troughs off the southwestern coast and in the western Atlantic and the strong zone of confluence in the central part of the United States.

The monthly mean 700-mb. chart for January 1957 (fig. 1) was compared with corresponding maps for each January since 1933. There were only three instances in which large positive DN centers were observed in or near the Gulf of Alaska. The weather and circulation of these three Januarys, namely: 1937, 1949, and 1950, have been discussed in detail by Klein [5, 6] and Namias, [7, 9].

January 1937 was cold west of the Mississippi River and warm to the eastward. The precipitation pattern was similar to that of 1957, except that amounts in excess of 20 inches were reported in the Ohio Valley, where serious floods occurred. A strong DN flow from the south in the eastern United States and a ridge off the east coast were the major circulation differences from 1957.

January 1949 was very much like January 1937. It was also cold in the West and warm in the East. Heavy precipitation covered most of the United States. There was a ridge over the east coast and a strong DN flow from the western Gulf of Mexico.

In January 1950 the major positive DN field lay over the eastern Aleutians. Cold air was confined to the Far West and the northern Plains States, with the balance of the United States above normal in temperature. Precipitation was heavy in the East and the Northwest. Principal circulation differences from January 1957 included a more intense west coast trough, a moderate ridge along the east coast, and a strong positive DN center over the Middle Atlantic States.

All the three months briefly noted above were predominantly cold in the western part of the United States and warm in the East. If one can single out the one feature which was common to those three months and conspicuously absent in January 1957, it is the ridge in the East. In January 1957 the pool of cold Canadian air (shown in fig. 4), made repeated invasions into the United States. This may have been partly responsible for the absence of a 30-day mean ridge along the east coast.

When the Gulf of Alaska DN center is used as an anchor point, Martin's anomaly charts [12] indicate below normal 700-mb. heights over Alberta about 80 percent of the time, with an associated area of above normal heights over New England about 60 to 70 percent of the time. This was the predominant pattern of 700-mb. anomaly during the three Januarys, 1937, 1949, and 1950. In January 1957, however, these areas did not react in the expected way to the key area in the Gulf of Alaska, as shown by above normal heights in Alberta and below normal heights in New England in figure 1.

Grossly, then, it appears that each January of the three years discussed above was near average regarding its downstream arrangement of height departures from normal. January 1957, on the other hand, was somewhat anomalous in a DN sense downstream from the anchor point. Hence, the temperature, and to some extent, the precipitation anomalies in the United States deviated from the "average" observed in January 1937, 1949, and 1950. This "average" pattern was achieved, however, during the fourth week of January 1957 (fig. 9), when both the weather and circulation over the United States were quite similar to that observed during the three analogous Januarys.

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A STORM OVER THE PLATEAU, JANUARY 20–21, 1957

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1. INTRODUCTION

The large-amplitude ridge in the eastern Pacific Ocean (described by Stark [11] in the preceding article) caused most of the storms moving eastward across the western Pacific Ocean to be diverted northward over the Bering Sea or western Alaska during January 1957. This pattern also was favorable for cyclogenesis over the area to the northeast of the Hawaiian Islands. In this paper one of these storms is discussed from its arrival near the coast of Oregon until it reached the Central Plains States. Prior to arrival off the west coast, the storm had followed a circuitous path across the eastern Pacific Ocean. As the storm stagnated near the mouth of the Columbia River, its energy caused cyclogenesis which moved eastward across southern Oregon, southern Idaho, and Wyoming, reaching northeastern Colorado during the 24-hour period. An attempt will be made to describe the weather and changes associated with the movement of this storm.

2. ANTECEDENT CONDITIONS

The week preceding the arrival of the storm off the Pacific Coast was characterized by a long-wave trough at the 500-mb. level persisting near 70° W. as shown on both the Hovmöller [6] diagram and the Fjørtoft [4] mean flow charts. During most of the same period long-wave ridges had persisted near 20° W. and 150° W. This unusually long wavelength prevailed at higher latitudes over all of the Northern Hemisphere during this period. At lower latitudes a much shorter stationary wavelength existed because the mean zonal wind speed was not of sufficient magnitude to support the wavelength which prevailed at the higher latitudes.

A check of the mean zonal wind speed as derived from the Rossby [9] long-wave formula showed a value of about 62 knots for a stationary wavelength of 130° longitude at 50° N. If the refinements suggested by Haurwitz [5] are included in the computations the value of the zonal wind speed necessary for equilibrium is reduced to about 55 knots. These derived values were compared to the average westerly component as measured on the Fjørtoft space mean flow charts. The measured values averaged near 50 knots, with values exceeding 100 knots in the vicinity of the long-wave trough over southeastern Canada.

In association with a 500-mb. lower-latitude trough that persisted over the eastern Pacific Ocean during this same period, two surface Lows developed and moved northeastward toward the Oregon–Washington coast. Mild maritime air in advance of these storms maintained above normal temperatures over the Pacific Coast States and southern Plateau region. In portions of Arizona and New Mexico temperatures were as much as 12° F. above normal. In contrast, the strong northwesterly flow over the Northern Plains States and the northeastern portion of the United States maintained below normal readings with some departures over South Dakota exceeding 15° F. [13].

3. STORM DEVELOPMENT

PRIOR TO JANUARY 20

On January 14, a new Low center began to develop northeast of the Hawaiian Islands about 600 miles west of the preceding two storms. This storm moved north-northeastward for about 48 hours with only minor intensification. During the next 18 hours the Low swerved westward and deepened as it came more nearly under the influence of an intense Low aloft. By January 17, the surface Low had recurved northward as the circulation aloft moved northward around the west side of the blocking High in the Gulf of Alaska. Intensification of the ridge to the west of the Low aloft forced it and the accompanying surface system eastward toward the west coast of North America. During the northward movement, the surface Low underwent cyclolosis in sympathy with the weakened cyclonic circulation aloft.

Figure 1 shows the development of the trough aloft as it moved from near 150° W. on January 17 to near 120° W. on January 20. The associated weakening of the ridge to the east of this trough and the intensification of the one to the west should be noted.

The surface Low underwent cyclogenesis as it moved eastward from Ship Papa (50° N., 145° W.). This was due in part to the advection of cyclonic vorticity aloft into the vicinity of the storm and "digging" as described by Wobus [16]. On the 500-mb. chart for 0300 GMT, January 19, a current of 50-knot winds moving out of Alaska toward a col necessitated a crossing of the winds

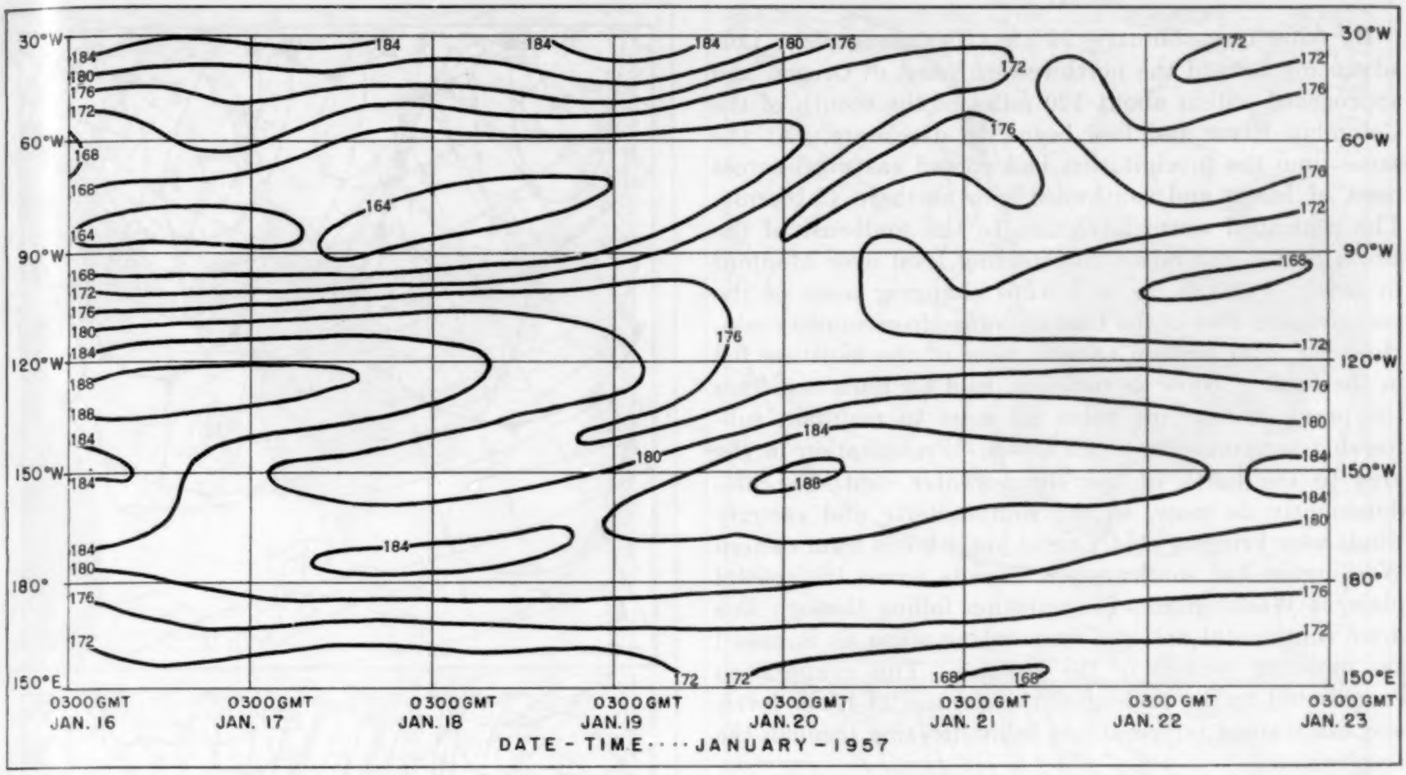

FIGURE 1.—Hovmöller diagram representing a cross section of the 500-mb. constant pressure chart from 30° W. to 150° E. during the period 0300 GMT, January 16, to 0300 GMT, January 23, 1957. Height values are in hundreds of feet.

toward higher contours and resultant slowing until they were in equilibrium with the actual gradient.

As the surface storm deepened and moved steadily toward the Oregon Coast, it advected increasing amounts of moisture over the Pacific Northwest. By 1230 GMT, January 19, the overcast preceding the storm had overspread nearly all of Oregon and Washington. Within another six hours precipitation had begun, primarily as snow, over western Oregon and Washington. South of the latitude of the storm center the winds in advance of the Low soon effected sufficient warming to change the precipitation to rain.

Figure 2 depicts the mean isotherm pattern which existed at 0300 GMT, January 19 prior to the arrival of the storm at the Pacific Coast. At that time a small 200-foot negative departure from normal in the thickness of the 1000–500-mb. layer indicated the extent of the colder air accompanying the storm center over the eastern Pacific Ocean. Meanwhile, the larger negative anomaly that was to play a prominent role in the development of this storm and the subsequent readjustment of the broad-scale features was located over northwestern Canada. The huge negative anomaly, which covered the area east of the Mississippi River at this time, marked the remnant of a retreating surge of cold air which had persisted over much of the eastern portion of the United States during the preceding weeks of January. The positive departure over Alberta and Saskatchewan was to be strengthened as warm advection ahead of the Pacific Low moved northeastward and tended to overspread the existing anomaly. It was this push of warmer air which later was to move eastward and produce mild temperatures in Washington, D. C., for the Presidential inauguration and a January thaw over the New England States.

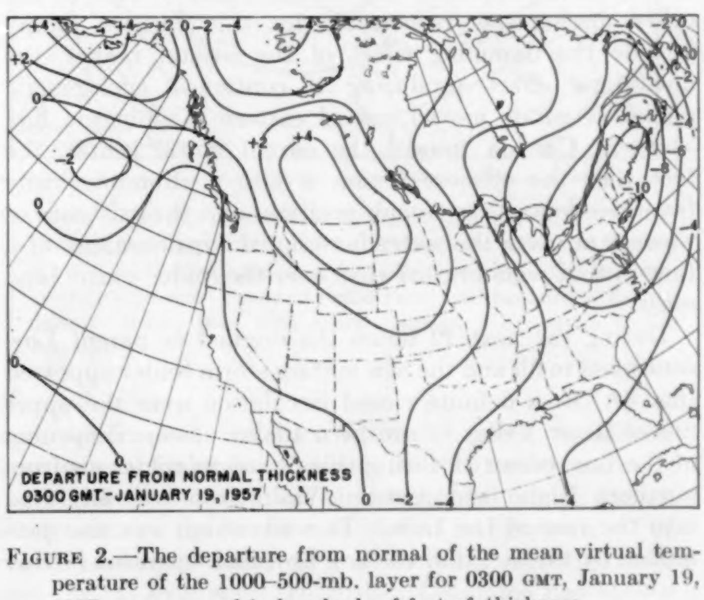

FIGURE 2.—The departure from normal of the mean virtual temperature of the 1000–500-mb. layer for 0300 GMT, January 19, 1957, as expressed in hundreds of feet of thickness.

JANUARY 20–21

By 0300 GMT, January 20 (fig. 3A) the surface Low advancing toward the northwestern coast of Oregon had approached within about 120 miles of the mouth of the Columbia River and had begun to decelerate. At the same time the precipitation had spread eastward across most of Idaho and southward into northern California. The continued warm advection to the southeast of the storm center had raised the freezing level over Medford to nearly 4,500 ft. m. s. l. thus changing most of the precipitation west of the Cascade range from snow to rain. However, over eastern Oregon most of the moisture fell in the form of snow as sufficient cold air remained from the previous stagnant polar air mass to maintain subfreezing temperatures at all levels. Precipitation in the area to the north of the storm center continued predominantly as snow, as the southeasterly and easterly winds were bringing colder air at lower levels from eastern Washington and southwestern Canada across the coastal plain of Washington. Precipitation falling through this drier continental air was evaporating some as it raised the moisture content of the airmass. This evaporation contributed to the cooling of the airmass at lower levels and maintained temperatures below freezing through the troposphere.

Despite the fact that the major concentration of cyclonic vorticity aloft continued to be accompanying the parent surface Low (see fig. 3B) a sufficient amount of thermal anticyclonic vorticity existed over southwestern Oregon to favor cyclogenesis. A new storm center is shown in figure 3A over the upper Willamette Valley, although the data were not sufficient to define a closed circulation. The region where the apparent cyclogenesis occurred was favorable for trough development because the southwesterly winds aloft were moving downslope on the east side of the coastal ranges. This type of redevelopment inland has been noticed frequently by the authors as major storms approach the Pacific Coast. Some of the other mechanisms responsible for this "center jump" include the damming effect of the coastal ranges, the downslope effect producing a continued cyclogenetic region as winds moved out of eastern Washington and southern Canada toward the parent storm center, the fact that the offshore region is also a climatologically favorable long-wave trough position, and the existence of warmer air over the water favoring the maintenance of a Low in that region rather than over the colder winter land mass.

During the next 12 hours the original or parent Low continued to fill and the new surface storm center appeared (fig. 4A) as a definite closed circulation over the upper Snake River Valley in southern Idaho. Some deepening of the Low occurred during this period as colder air from northern Idaho and eastern Washington was advected into the rear of the Low. This advection was also permitted by the fact that the new Low had separated farther

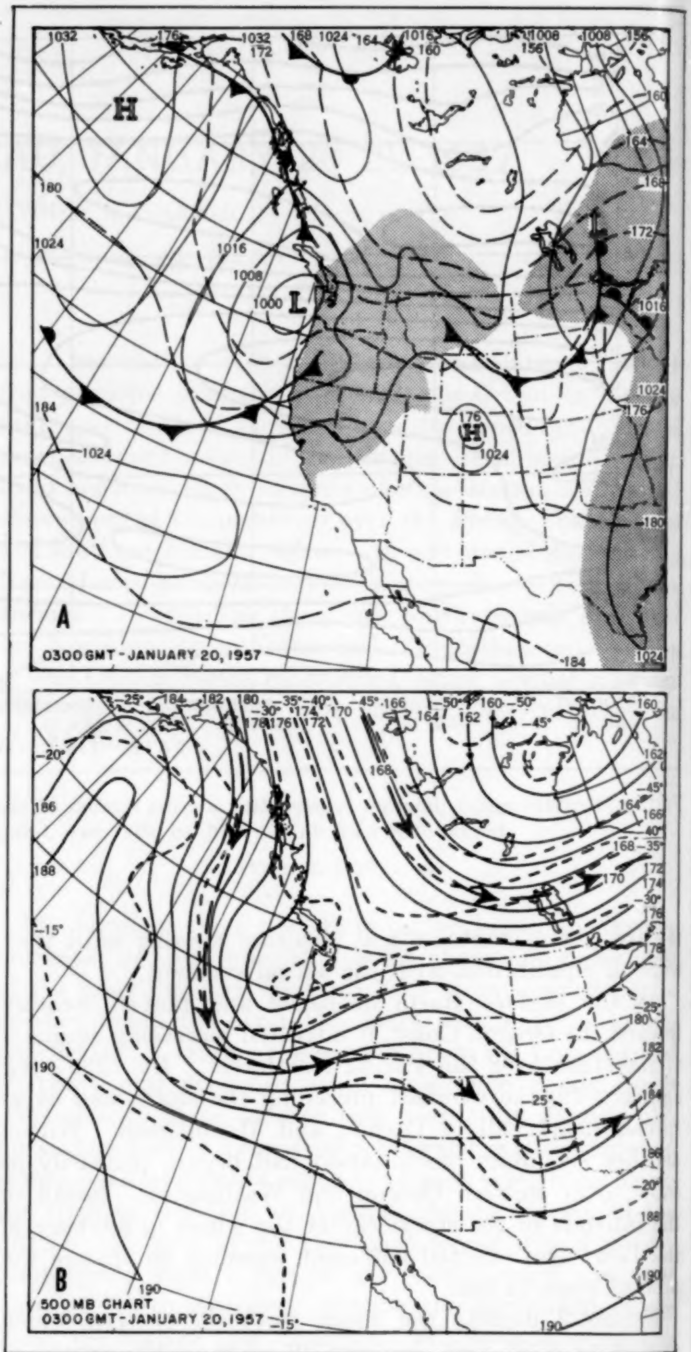

FIGURE 3.—Synoptic patterns for 0300 GMT January 20, 1957. (A) Surface chart (solid lines) with 1000–500-mb. thickness (dashed lines). Shaded area is essentially overcast. (B) 500-mb. chart with height contours (solid lines) and isotherms (dashed lines). Heavy lines with arrows indicate the position of the 300-mb. jet.

from the parent Low. Precipitation continued to spread eastward to central Wyoming and southward through California to the southern end of the San Joaquin Valley. The cloudiness ahead of the storm advanced to produce overcast conditions 300 to 400 miles farther east as sufficient moisture had been carried by the westerly

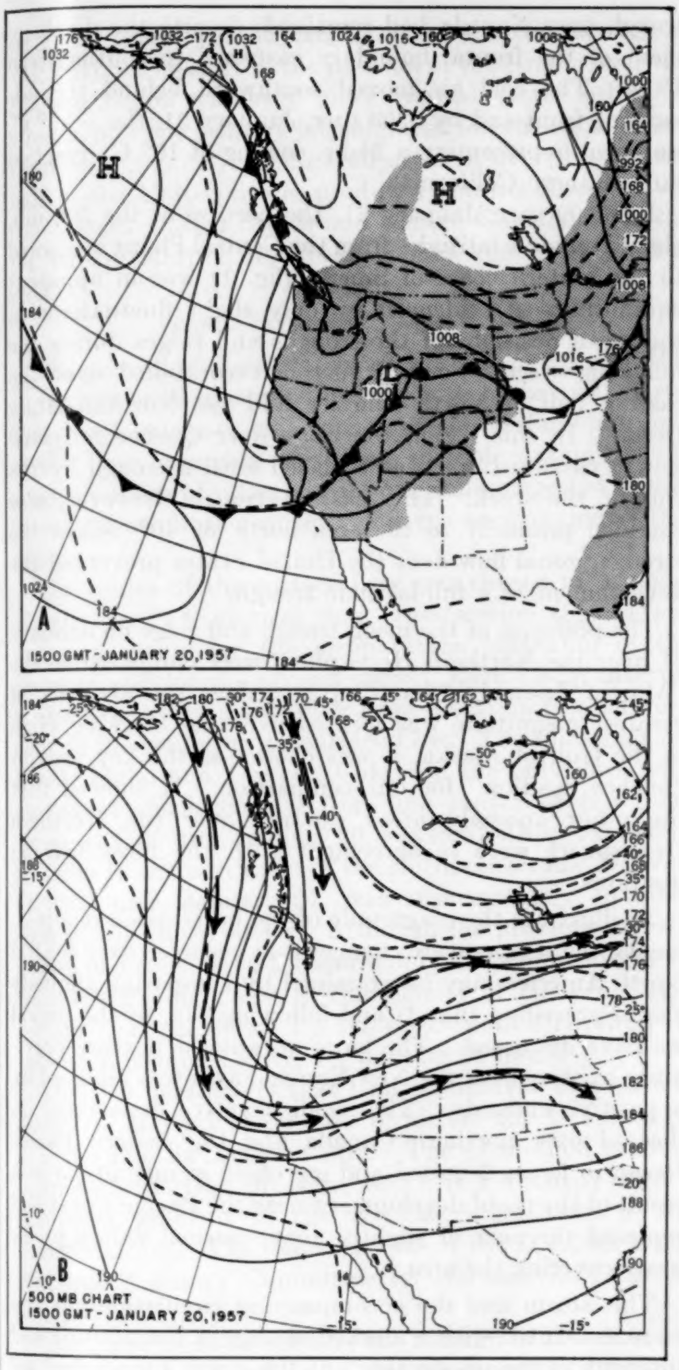

FIGURE 4.—Synoptic patterns for 1500 GMT, January 20, 1957. (A) Surface chart (solid lines) with 1000–500-mb. thickness (dashed lines). Shaded area is essentially overcast. (B) 500-mb. chart with height contours (solid lines) and isotherms (dashed lines). Heavy lines with arrows indicate the position of the 300-mb. jet.

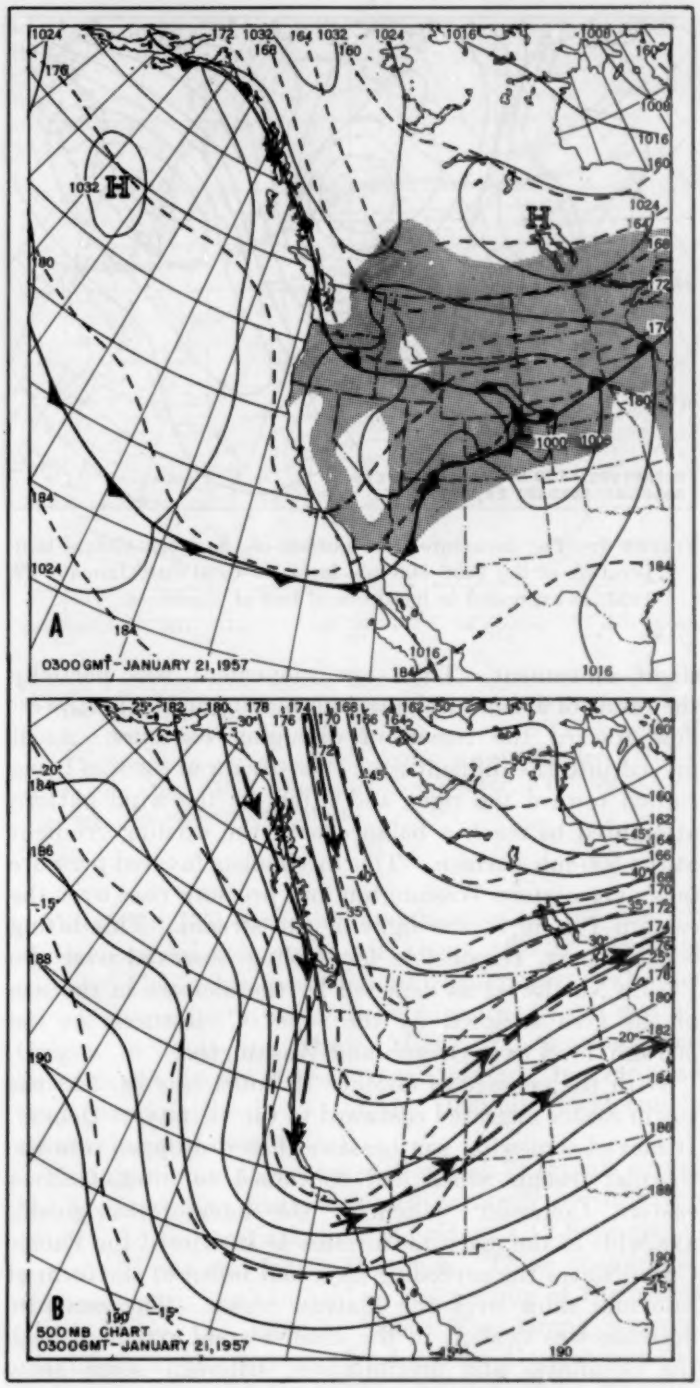

FIGURE 5.—Synoptic patterns for 0300 GMT, January 21, 1957. (A) Surface chart (solid lines) with 1000–500-mb. thickness (dashed lines). Shaded area is essentially overcast. (B) 500-mb. chart with height contours (solid lines) and isotherms (dashed lines). Heavy lines with arrows indicate the position of the 300-mb. jet.

winds aloft as far as southwestern Arizona and northeastern Colorado.

Aloft, the short-wave pattern had advanced eastward with the area of maximum cyclonic vorticity (fig. 4B) now located near the Idaho-Oregon border. During the same period, the northwest winds over the Rocky Mountains, which produced very little downslope conditions over eastern Colorado, backed to the west-southwest, favoring the intensification of the thermal trough immediately east of the Rockies as shown in figure 4A. The area of strongest difluence indicated on the 0300 GMT chart (fig. 3) over southern British Columbia had shown

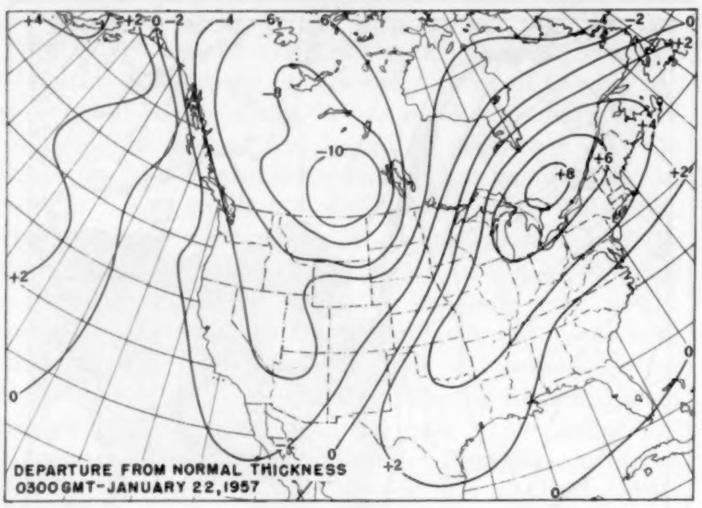

FIGURE 6.—The departure from normal of the mean virtual temperature of the 1000–500-mb. layer for 0300 GMT, January 22, 1957, as expressed in hundreds of feet of thickness.

slight movement. This slow movement was partially the result of a short-wave trough moving in the northwest flow toward the region of diverging contours. As it moved into the difluent zone this stream of air was being turned toward the right and lifted, as the wind pattern attempted to reach a balance with the existing gradient at the 500-mb. surface. This mechanism favored pressure falls over eastern Washington and pressure rises over the eastern Pacific to the right of the stream. This lifting was, in part, responsible for cooling observed over the Pacific Northwest as depicted by the increase in the size of the area enclosed by the −30° C. isotherm at the 500-mb. level over Oregon and Washington.

With the passage of another 12 hours (see fig. 5A) the storm center migrated eastward to the vicinity of Denver. It moved somewhat southeastward as it dropped into the thermal trough which had continued to intensify over eastern Colorado. Much of the moisture, originally available in the maritime airmass as it entered the Pacific Coast States the preceding day, had fallen in the form of rain and snow over the Plateau region. The moisture decrease was evident in the smaller areal extent of both the cloudiness and precipitation, although some snow showers continued in and along the western slopes of the central Rocky Mountain area. At this time the leading edge of the overcast preceded the frontal zone and associated precipitation by only 100 to 200 miles.

The difluent region on the 500-mb. chart over British Columbia at 1500 GMT had become much less prominent by 0300 GMT, January 21 (fig. 5B) due to the movement of the short wave in that current eastward into the Alberta area. Meanwhile the secondary area of marked difluence that existed in the vicinity of Vancouver Island (fig. 4B) had moved southward and intensified until it was the primary delta zone on the 500-mb. chart for 0300 GMT, January 21. In association with this difluent area a trough over Nevada had remained, despite the displacement of the frontal boundary eastward to southeastern Utah. The cold air moved southward behind the advancing front and by 0300 GMT, January 21, the −25° C. isotherm, representing a 24-hr. cooling of 10° C., reached into southern California.

By 0300 GMT, January 21, the portion of the 500-mb. chart at middle latitudes from the Central Plains westward to the eastern coast of Siberia (fig. 1) was in apparent equilibrium as evidenced by only slight fluctuations in the mean positions of the troughs and ridges during the following week. Some adjustment continued over the eastern half of North America and the North Atlantic Ocean. In this region the ridge over Quebec migrated slowly eastward and was replaced with a trough by the end of the week. This eastern trough, however, was confined primarily to the area north of 40° N. as the stronger zonal flow over the United States prevented the development of a full-latitude trough.

The positions of the mean trough and ridge on January 21 over the Northern Hemisphere were compared to the "Martin Anomaly Charts" [12]. Since the anomaly of greatest magnitude was located over the blocking High in the Gulf of Alaska, it was chosen as the key area or "anchor position" for our comparison. It showed that the other anomaly areas existing over the Northern Hemisphere were in agreement with the most favored positions.

To illustrate the magnitude of the broad-scale readjustments, the temperature changes that occurred over central North America may be examined by comparing anomaly charts preceding (fig. 2) and following (fig. 6) the period we have discussed. The large negative departure previously existing over the New England area was replaced by a positive anomaly. The small negative departures indicated over northern Canada and the eastern Pacific Ocean in figure 2 united and increased in magnitude as a result of the rapid development near the Pacific Coast and replaced the near or slightly above normal values previously covering the area.

This storm and the accompanying circulation changes were associated with a marked change in the position and intensity of the jet stream. As the storm approached the Pacific Coast on January 20, the primary jet stream was located from northeastern Alaska across northeastern Alberta and southern James Bay to the Canadian Maritime Provinces, then northeastward across the North Atlantic (fig. 3B). At the same time a secondary jet stream was moving out of southern Alaska southward across northern California. This latter branch coursed mainly eastward at mid-latitudes across the United States except for some southward displacement over the Central Plains. During the next 24 hours the increasing northerly flow off the Pacific Coast was accompanied by a westward shift of the jet stream across western Canada, while during the same interval the northerly jet stream

over the ocean was displaced toward the coastal regions (fig. 4B). The shift in the position of the stream over the Plateau region was even more marked as the other jet stream, now the primary jet, migrated to extreme southern California (fig. 5B). This readjustment over the western half of the United States produced marked changes over the eastern United States and eastern Canada, with the jet stream shifting northward about 400 miles in that area.

VERTICAL DEVELOPMENT, JANUARY 20–21

The preceding discussion of events associated witn this storm has been concerned mainly with horizontal charts. The very fortunate coincidence of the surface positions of the Low occurring very close to raob stations at the synoptic times of upper-air observations suggested a brief investigation of the vertical changes accompanying this storm.

The center of the surface Low was chosen for a point of reference. A vertical time cross section (fig. 7) was prepared, using for the ordinate the logarithm of the pressure and for the abcissa, time. Each 12-hr. interval is represented by a sounding from a station located very near to the center of the surface Low. The soundings for Boise, Idaho and Denver, Colo. are the only ones with important displacements from the center of the Low. Boise, at 1500 GMT, January 20, was located approximately 80 miles to the northwest of the storm center and Denver, at 0300 GMT, January 21, was approximately 40 miles west of the storm center. Although the previous investigation had considered the storm only during its movement from the Pacific Coast to the vicinity of Denver, Colo., certain changes shown by the cross section required its extension beyond Denver for another 24 hours.

The two parameters that lend themselves to a concise portrayal of vertical columns of air are the D values [1] and the free air temperatures. The D method is more suitable to portray pressure, which is a quantity with a dominant gradient in the vertical rather than in the horizontal [10]. The reference base of the D values is the National Advisory Committee for Aeronautics (NACA) atmosphere.

Along any isobaric surface, the minima in D values are the troughs in the plane of the cross section (vertical) and the maxima are the ridges. Stability conditio is are indicated by the rate of increase or decrease of D values. Warming, then, is indicated by decreasing negative departures (or increasing positive departures), and, conversely, cooling by increasing negative departures (or decreasing positive departures). Because there is a certain relationship between D values and the mean virtual temperature, the maximum D values in the positive sense indicate air of lower density and, conversely, maximum D values in the negative sense air of higher density. Free air temperatures are included in the cross section because they are frequently used as an index of horizontal advective changes.

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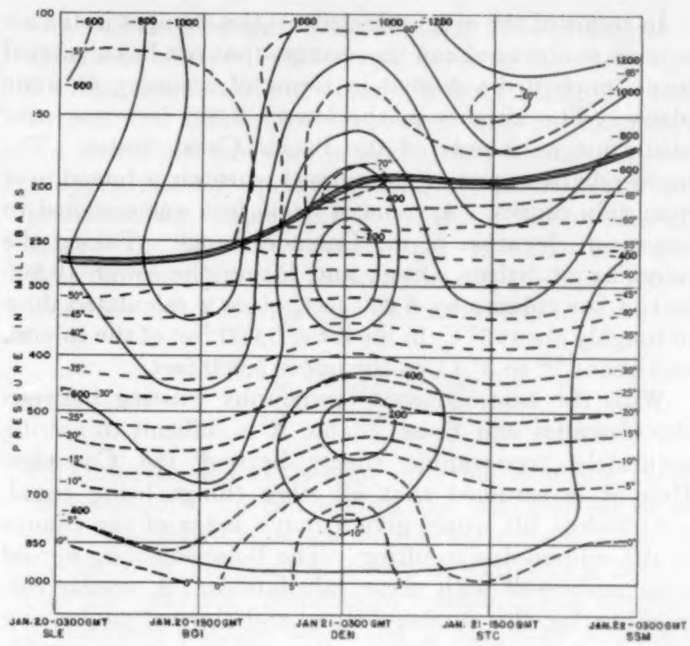

FIGURE 7.—Time cross section through the approximate center of the surface low. D values (solid lines) are drawn for every 200 feet. Isotherms (dashed lines) are drawn for every 5° C. The tropopause is shown as a double dot shaded line. SLE= Salem, Oreg., BOI=Boise, DEN=Denver, STC=St. Cloud, and SSM=Sault Ste. Marie.

Vederman [15] made an investigation of the changes of the vertical column of air above rapidly deepening storms. Unlike his cases, this particular storm exhibited no net deepening in its 48-hour movement from western Oregon to Sault Ste. Marie, Mich. Fluctuations were noted in the height of the 200-mb. surface, but for practical purposes the height of the 1000-mb. level can be assumed nearly constant.

Examination of this cross section (fig. 7) reveals a number of interesting features which certainly invite further study. In the vertical there is evident a 12-hour cycling pattern of rise and fall in D values. These changes, for the most part, are confined to the portion of the atmosphere above the 400-mb. level. The strong warming maximum at the 500-mb. level in the Denver sounding may be accounted for mostly by downslope warming. But it is interesting to note that alternate cooling and warming occurs even at lower levels of the column although the changes are not so prominent as above the 400-mb. level. One inference which suggests itself is the diurnal effect. It may be, perhaps, that alternate advective cooling and warming occurred during the motion of the storm, but the rhythmic nature of this event makes this explanation difficult to accept. No attempt has been made to determine whether those density changes were due to vertical motion. On the isobaric surfaces, the maximum changes occurred between the 300-mb. and 150-mb. levels with perhaps the greatest change at 250 mb.

In terms of the orographic effect, the changes in the air column as observed and the changes that can be calculated leave much to be desired in terms of accuracy at some places. The airmass in the lowest 5,000 feet was near saturation as it entered the Pacific Coast States. The moist adiabatic process is assumed when air is forced over mountain ranges. A value of 5,000 feet was assigned to the mean elevation of the Cascade Range. Taking the sounding at Salem, Oreg., and lifting the lower 10,000 feet of the column by 5,000 feet, gives a calculated drop of roughly about 5° C. in the lower 5,000 feet of the column and about 2° to 3° C. in the upper 5,000 feet.

With the heterogeneous topography existing between the Cascades and Boise, Idaho, it is difficult to ascribe accurately topographic effects beyond the Cascades. Here it is assumed that all other things being equal, a 5,000-foot lift would give a rough index of the change in the column due to lifting. The Boise sounding agreed reasonably well with these calculations. A similar calculation for the further lifting and downslope heating of the air reaching Denver also resulted in reasonable agreement with the observed sounding.

One could argue from the foregoing discussion that the cyclical temperature changes in the layer below the 400-mb. level at Boise and Denver could be accounted for by the topographic effects. These effects would not account for the changes at Saint Cloud, Minn., and Sault Ste. Marie, although the cyclical changes were of smaller magnitude in these latter soundings.

While the D values change on the isobaric surfaces quite markedly, the free air temperature changes on the same surfaces are comparatively small. For example, at the 250-mb. level the maximum temperature change is 6° C., whereas the maximum D value change is 1,000 feet. A 6° C. change in the mean virtual temperature in the layer between 300 mb. and 250 mb. would result in a thickness change of slightly over 100 feet. Similarly a 15° C. change in temperature throughout the atmosphere between 250 mb. and 200 mb. would give a thickness change of less than 350 feet. This indicates that while the changes between adjacent isobaric levels were quite small, the vertical changes of large portions of the column were striking.

No attempt was made to find a physical basis for these changes and features. A closer study would probably reveal other relationships but neither time nor space allow their recognition in an article of this scope.

4. THE STORM TRACK

A comparison was made between the track of this storm and the published normal tracks of Bowie and Weightman [2], the California Institute of Technology [3] and Klein [8]. Following the system of [2] the storm discussed here would be classed as a North Pacific storm since it reached the Pacific Coast north of 40° N. A storm of this type normally shows an east-northeasterly track until it reaches the longitude of eastern Oregon, then turns toward the southeast until it reaches the Central Plains and recurves toward the Great Lakes area. The normal storm shows an average movement of about 900 miles in each 24-hour period. The path of the storm of January 20–21, 1957, agreed well both in direction and speed with these average qualities.

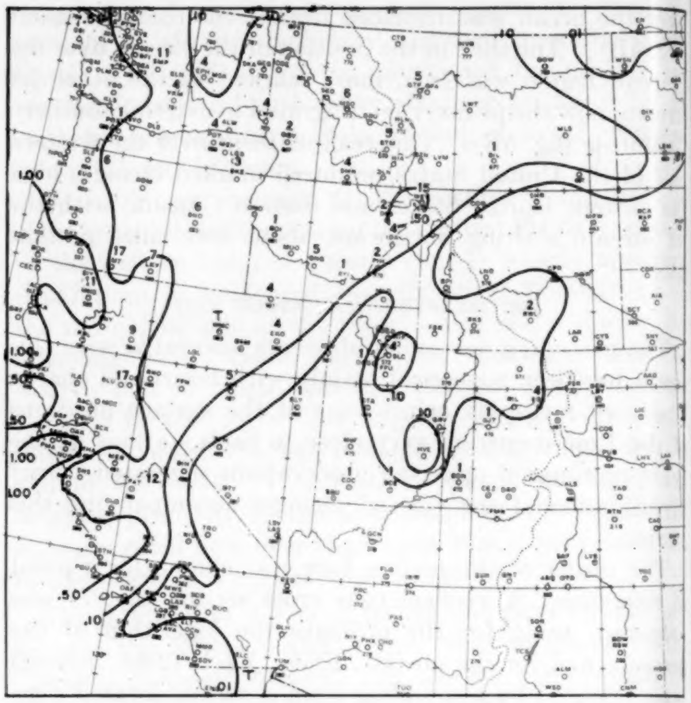

FIGURE 8.—Approximate precipitation totals for the period 1230 GMT, January 19, to 0630 GMT, January 21. Isohyets are drawn for 1.00 inch, 0.50 inch, 0.10 inch, 0.01 inch. Superimposed numerals indicate snow cover increase associated with the storm for the period ending 1230 GMT, January 21, 1957.

The January 1957 storm shows some similarities to the CIT type E storm although that is primarily a type of storm that occurs with stronger zonal conditions. The average storm tracks of Klein likewise show fair agreement with the actual track of this storm, although it must be remembered that these tracks of Klein represent composite tracks of many different types of storms as related to origin and direction of movement.

It might be expected that such a nearly "normal" storm would present little difficulty in the prediction of its movement and changes. This was borne out by a check of the verification scores of the surface prognostic charts prepared by the National Weather Analysis Center (NAWAC) to verify at 0030 and 1230 GMT, January 20 and 0030 GMT, January 21. Scores were better than the average for January 1957 and better than the 7-year mean for January. A check of the prognostic charts prepared by NAWAC and the thermotropic prognostic chart prepared by the Joint Numerical Weather Prediction Unit (JNWP) for the 500-mb. surface showed the same situation although the charts issued by JNWP were slightly better than those of NAWAC.

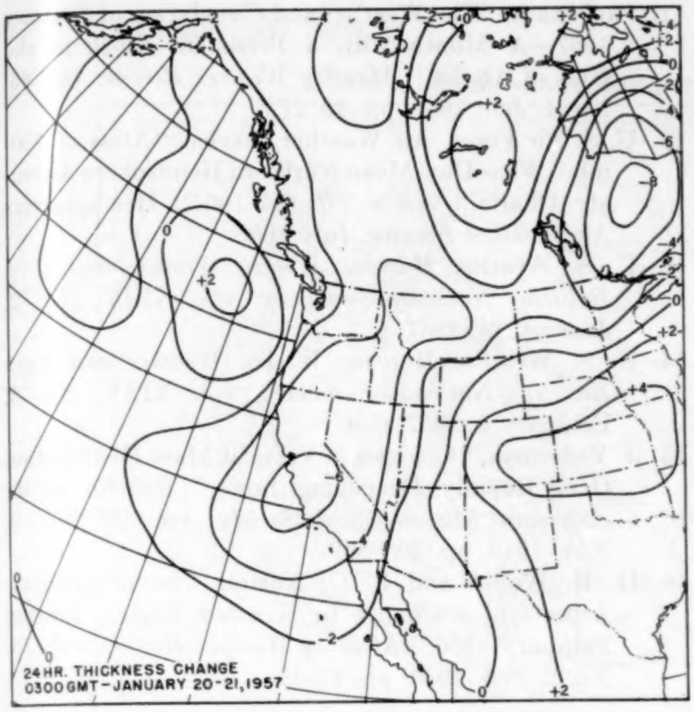

FIGURE 9.—Thickness change between 0300 GMT, January 20, and 0300 GMT, January 21, 1957, of the 1000–500-mb. layer in hundreds of feet.

5. PRECIPITATION AND TEMPERATURE

This storm brought rather widespread precipitation across much of the western Plateau but the heaviest amounts were confined to the immediate coastal areas south of the storm center. As shown in figure 8, the maximum amounts reported from this storm fell in northern California and southwestern Oregon, while a secondary maximum of over one inch was reported in the San Francisco Bay area. At most reporting points over 75 percent of the total precipitation received from the storm fell during an 18-hour period accompanying the frontal passage. The precipitation totals from this Low represented over the Plateau area about ⅓ to ½ of the total moisture received during the month [14]. Since a large portion of the precipitation at the higher elevations in the Sierra Nevada and Cascade ranges and to the east was in the form of snow, a substantial increase in the snow cover resulted. Some of the more significant increases reported included 17 inches at Crater Lake, Oreg., and Blue Canyon, Calif., 5 inches at Austin, Nev., and over 15 inches at West Yellowstone, Mont.

The initial surface temperature changes were not very spectacular since the new maritime airmass was not appreciably different in the lower levels from the existing stagnant continental airmass over the Plateau. Arctic air moved southward over that region during the following week and brought very sharp temperature drops with some all-time records being broken. The change in the thickness of the 1000–500-mb. layer is shown in figure 9 with a decrease of more than 600 feet (cooling) occurring over central California. Showalter (c. f. [7]) has pointed out that a 200-foot change in the 1000–700-mb. thickness is approximately equal to a change of 10° F. in the maximum surface temperature if the lapse rate remains constant. He has also shown that $Z_5=2Z_7-2F$, where Z_5 is the 1000–500-mb. thickness and Z_7 the 1000–700-mb. thickness and F is a measure of the stability of an airmass. Thus

$$\frac{\partial Z_5}{\partial t}=2\frac{\partial Z_7}{\partial t}-2\frac{\partial F}{\partial t}.$$

Because readings at 24-hour intervals eliminate diurnal considerations, we can neglect the last term $\partial F/\partial t$ and write the above equation in the finite form $\Delta Z_5=2\Delta Z_7$ for use over intervals of a day or two. This equation plus the previous temperature relationship is applicable if thickness changes are noted in the same airmass on consecutive days. This equation applied to the changes shown in figure 9 permits one to expect warning of 10° F. or more over Kansas and Oklahoma. A check of the surface temperature changes between the times of figures 3A and 5A shows rises of 10° to 15° F. in that area. Factors contributing to the differences between temperature changes expected over California from the above equation and those which actually occurred include: (a) a change of F over that region due to a change of airmass, (b) variations in cloudiness, (c) precipitation, and (d) wind. The actual changes over California during the period discussed above were limited to slight cooling at the higher elevations.

ACKNOWLEDGMENTS

We wish to express our appreciation to the staff members of NAWAC for their helpful suggestions. We also wish to thank the Daily Map Unit for their cooperation in drafting the figures published in this article.

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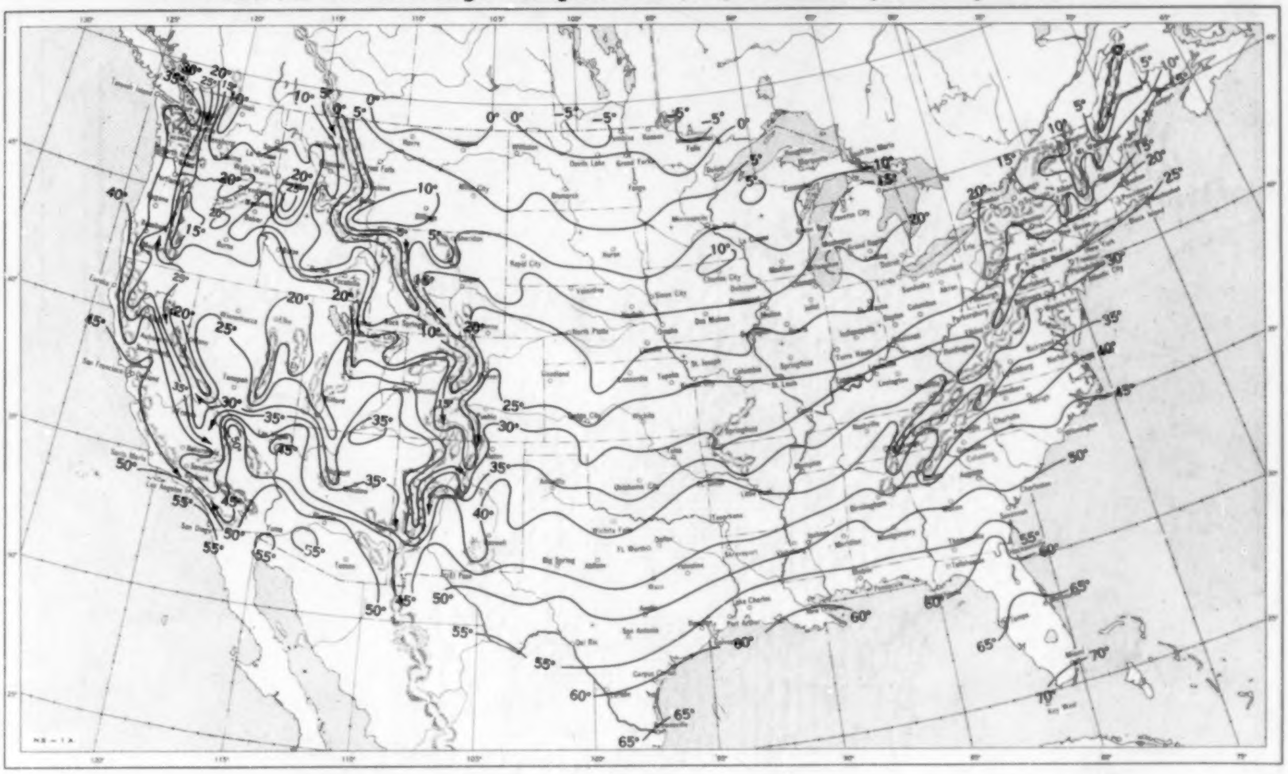
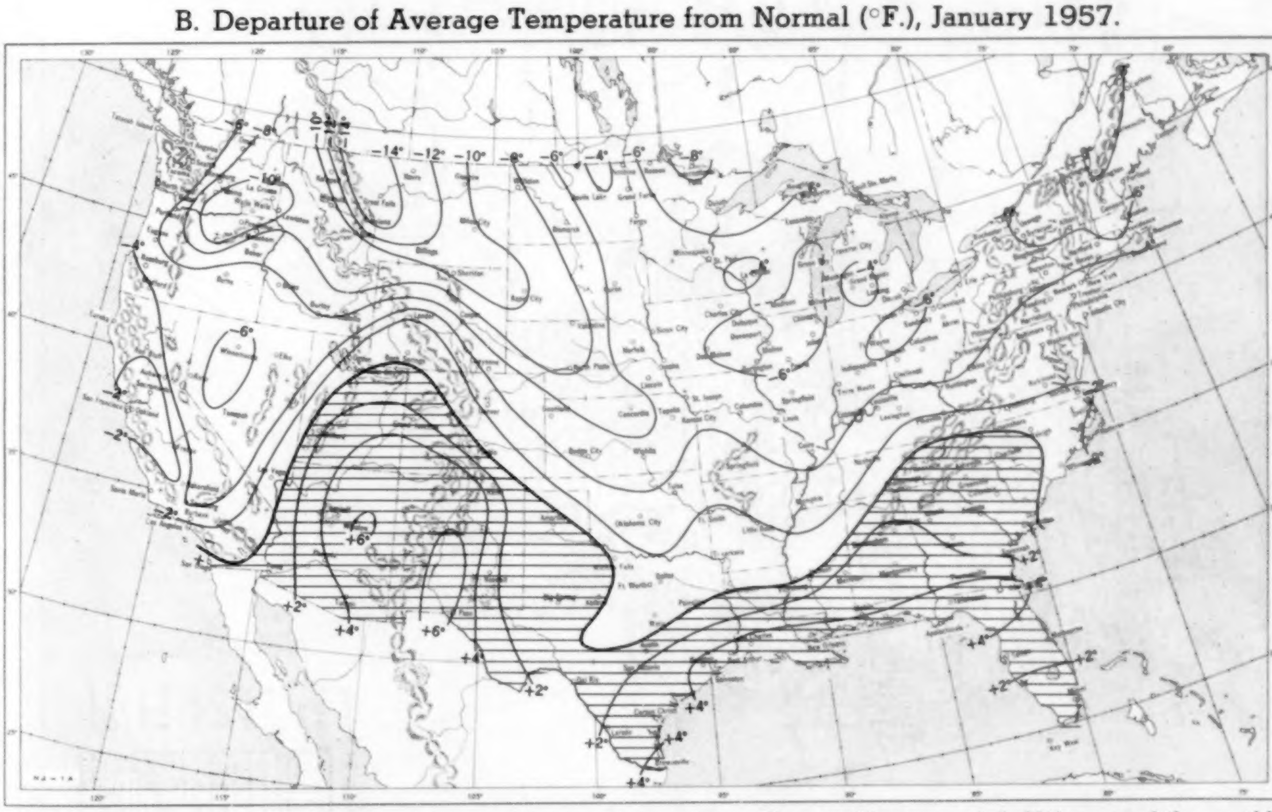
Chart I. A. Average Temperature (°F.) at Surface, January 1957.

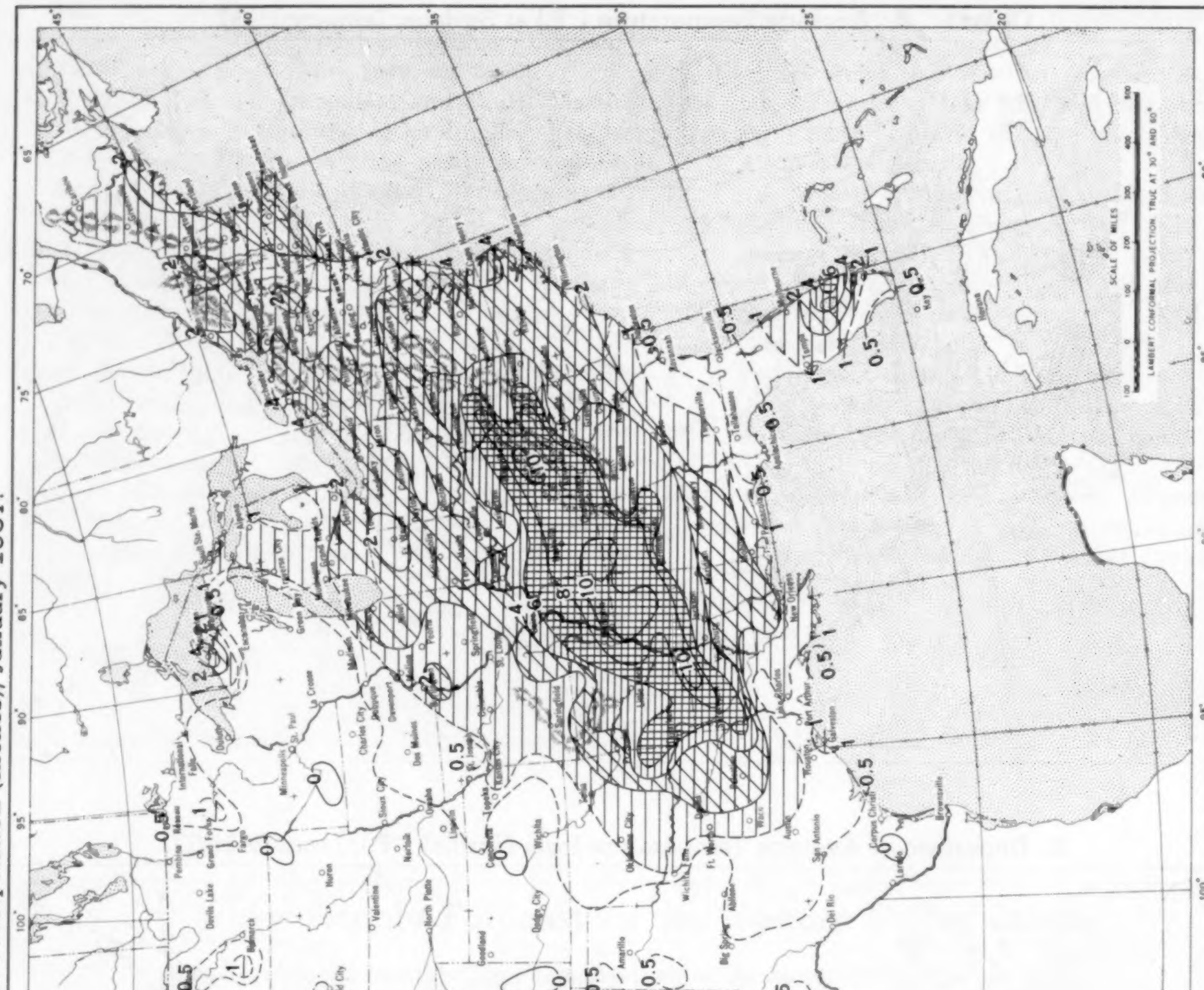


B. Departure of Average Temperature from Normal (°F.), January 1957.



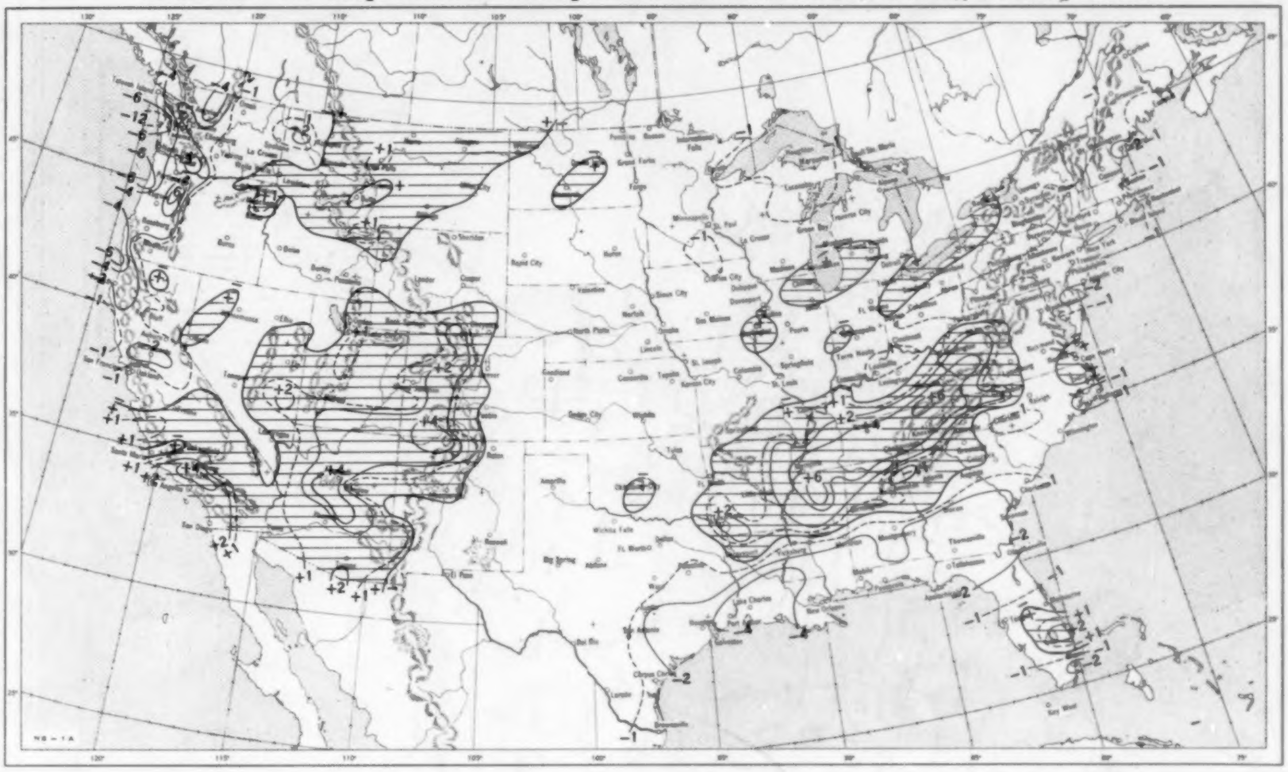
A. Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

Chart II. Total Precipitation (Inches), January 1957.

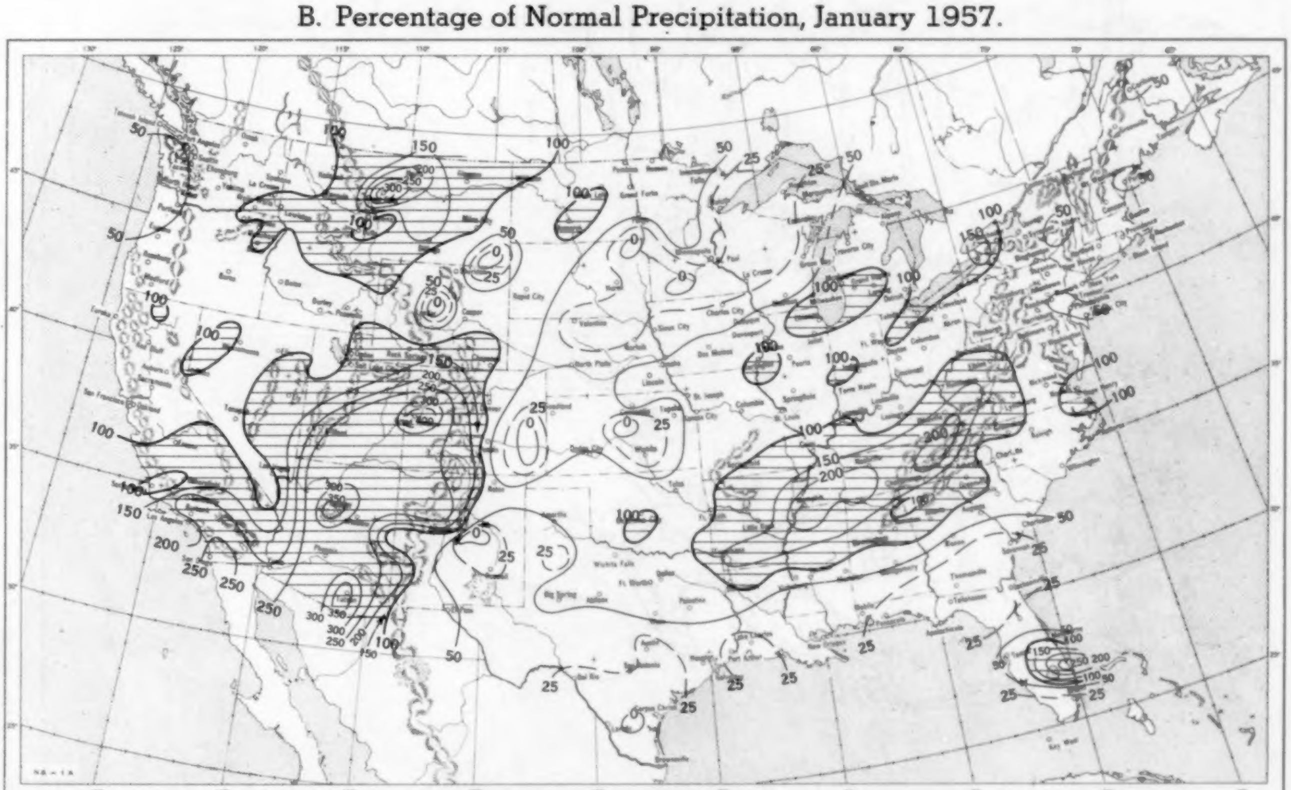


Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), January 1957.

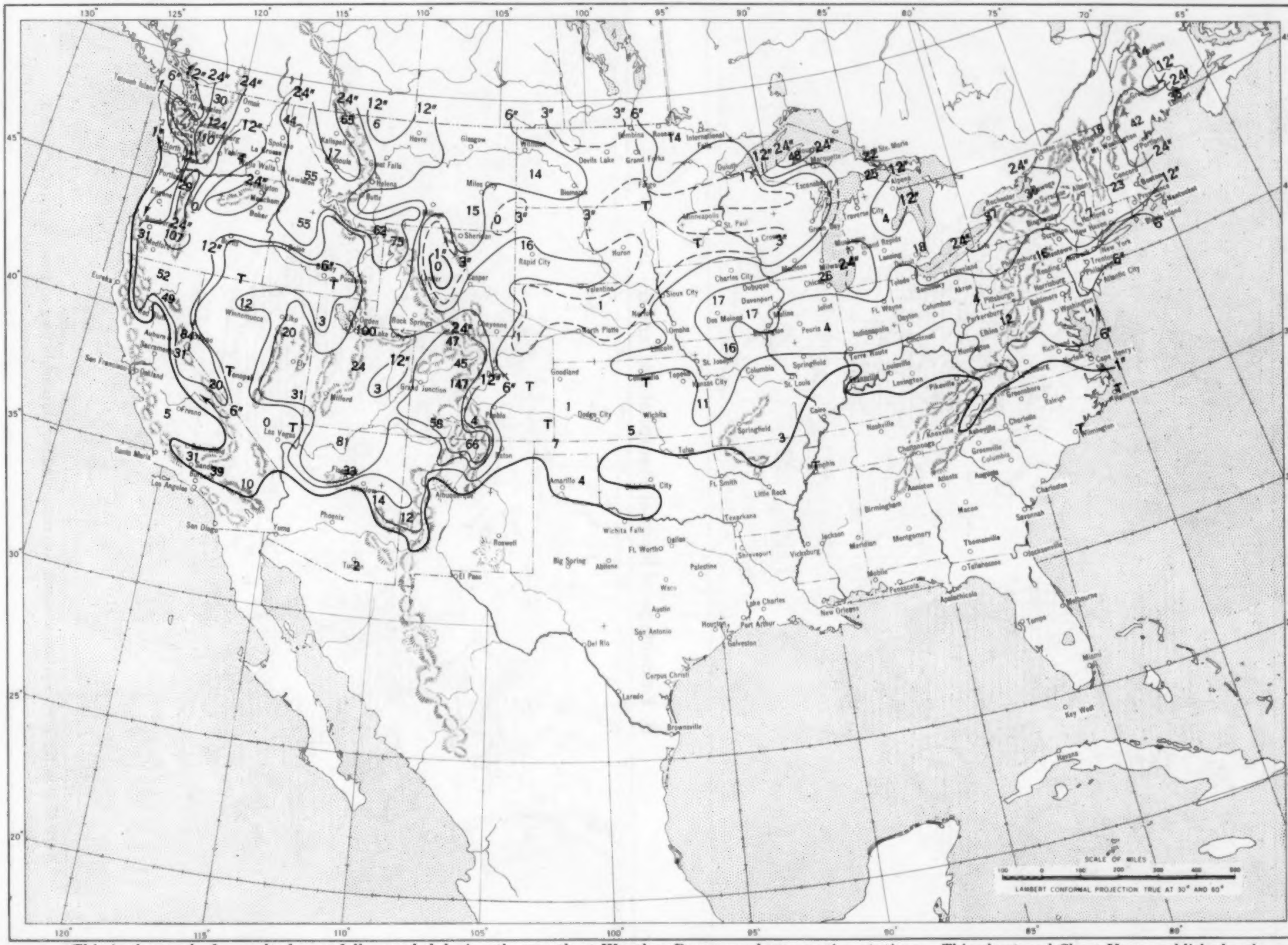


B. Percentage of Normal Precipitation, January 1957.



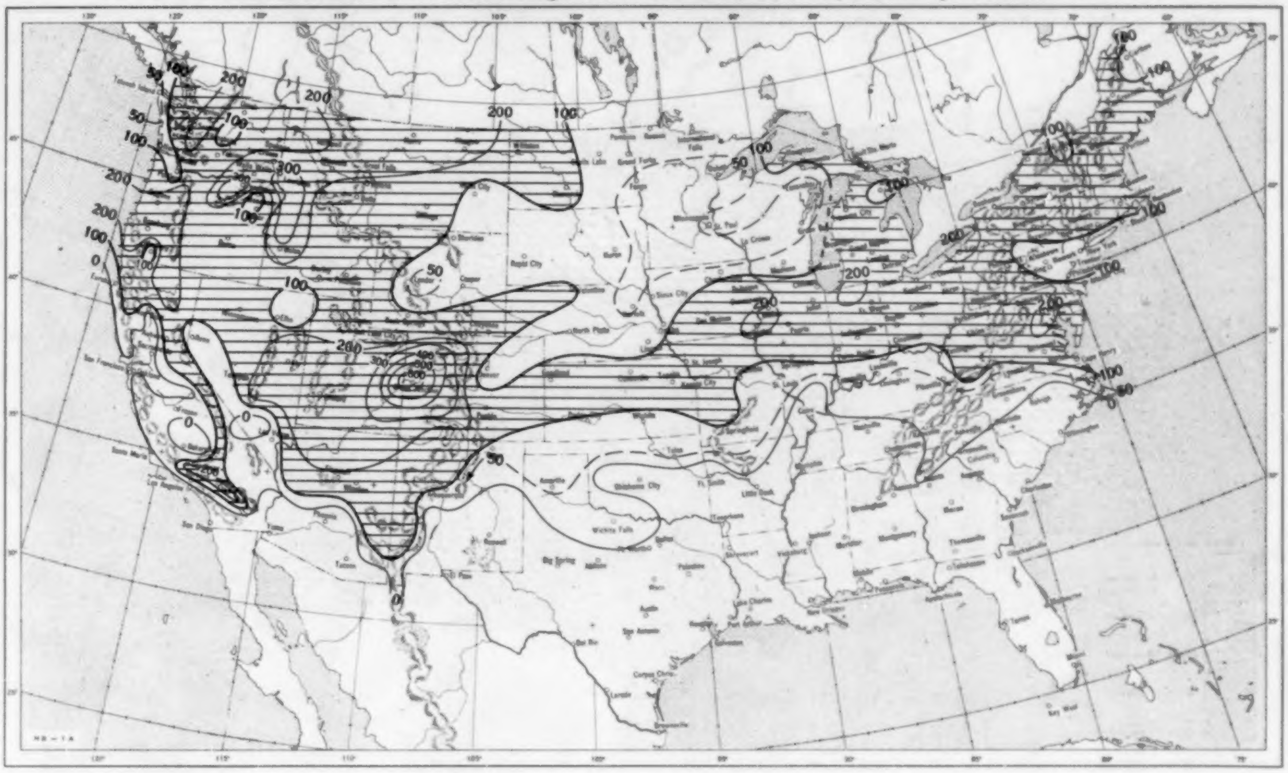
Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart IV. Total Snowfall (Inches), January 1957.

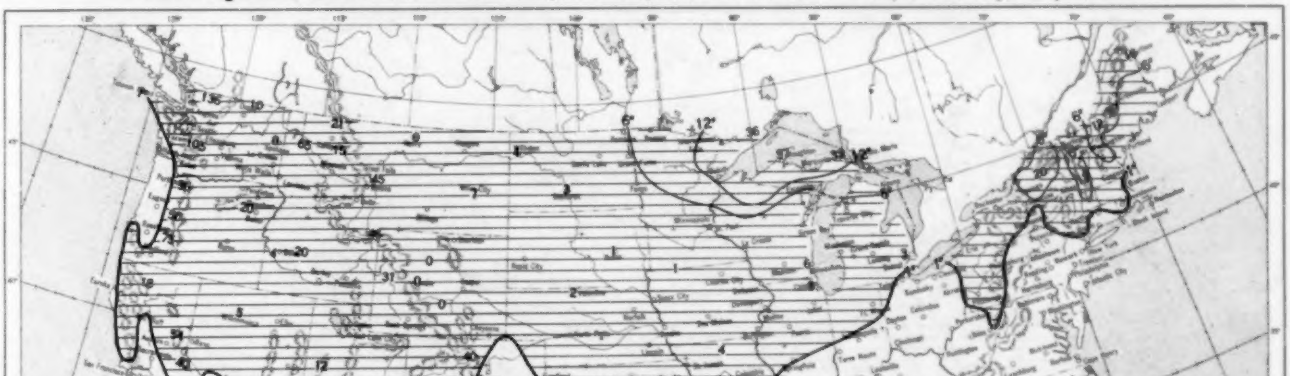


This is the total of unmelted snowfall recorded during the month at Weather Bureau and cooperative stations. This chart and Chart V are published only for the months of November through April although of course there is some snow at higher elevations, particularly in the far West, earlier and later in the year.

Chart V. A. Percentage of Normal Snowfall, January 1957.

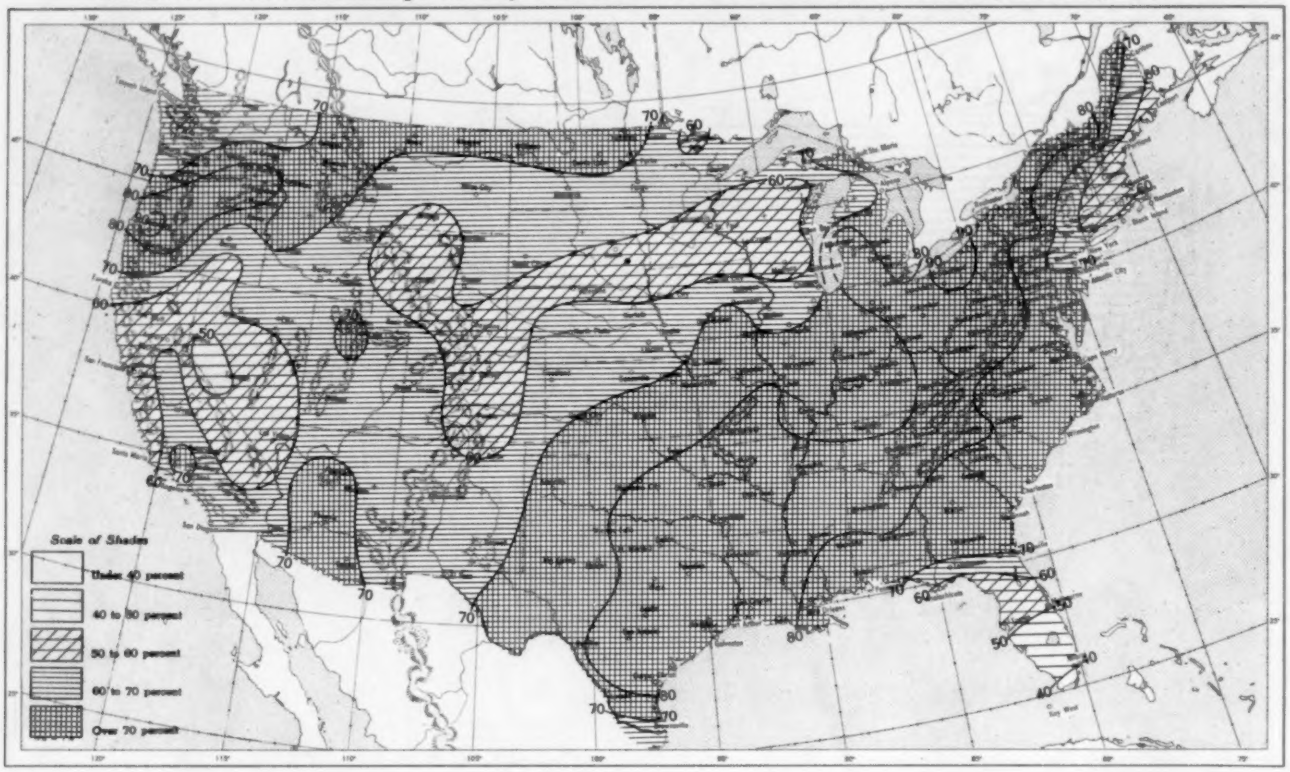


B. Depth of Snow on Ground (Inches). 7:30 a. m. E. S. T., January 29, 1957.

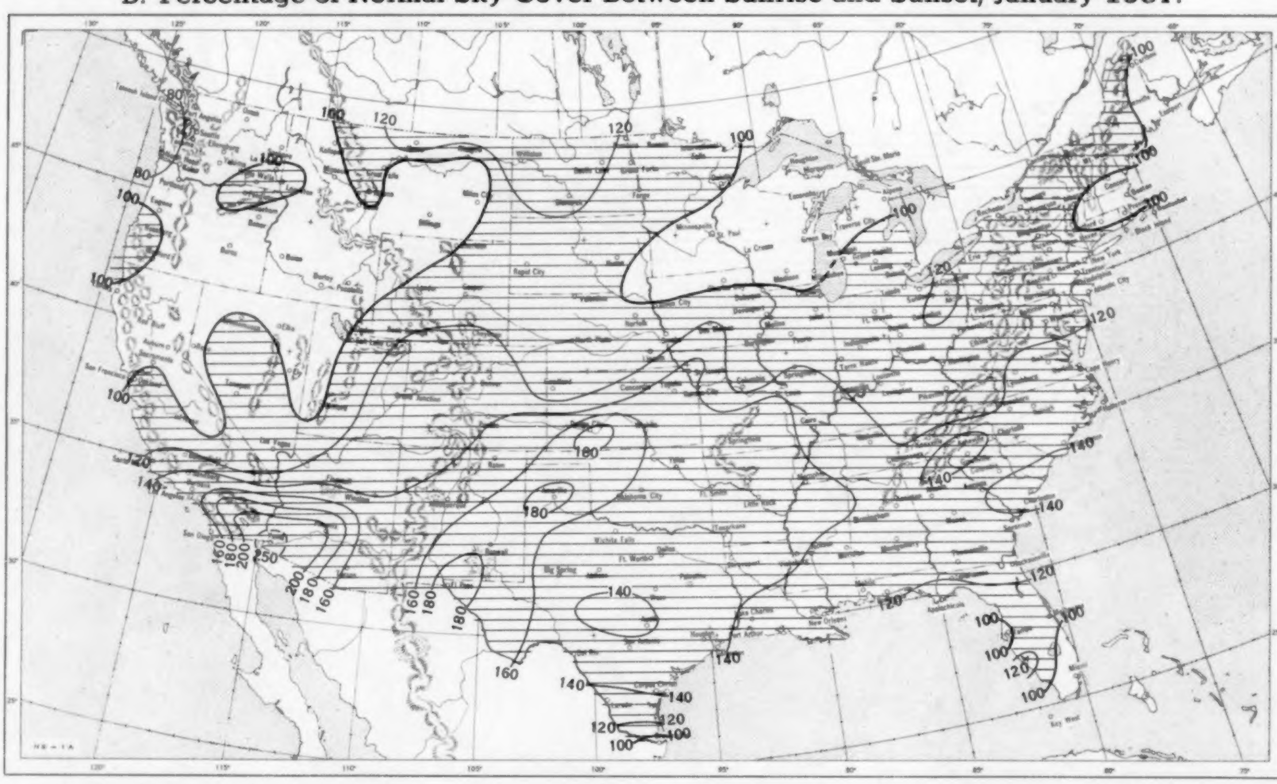


A. Amount of normal monthly snowfall is computed for Weather Bureau stations having at least 10 years of record.
B. Shows depth currently on ground at 7:30 a. m. E.S.T., of the Tuesday nearest the end of the month. It is based on reports from Weather Bureau and cooperative stations. Dashed line shows greatest southern extent of snowcover during month.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, January 1957.

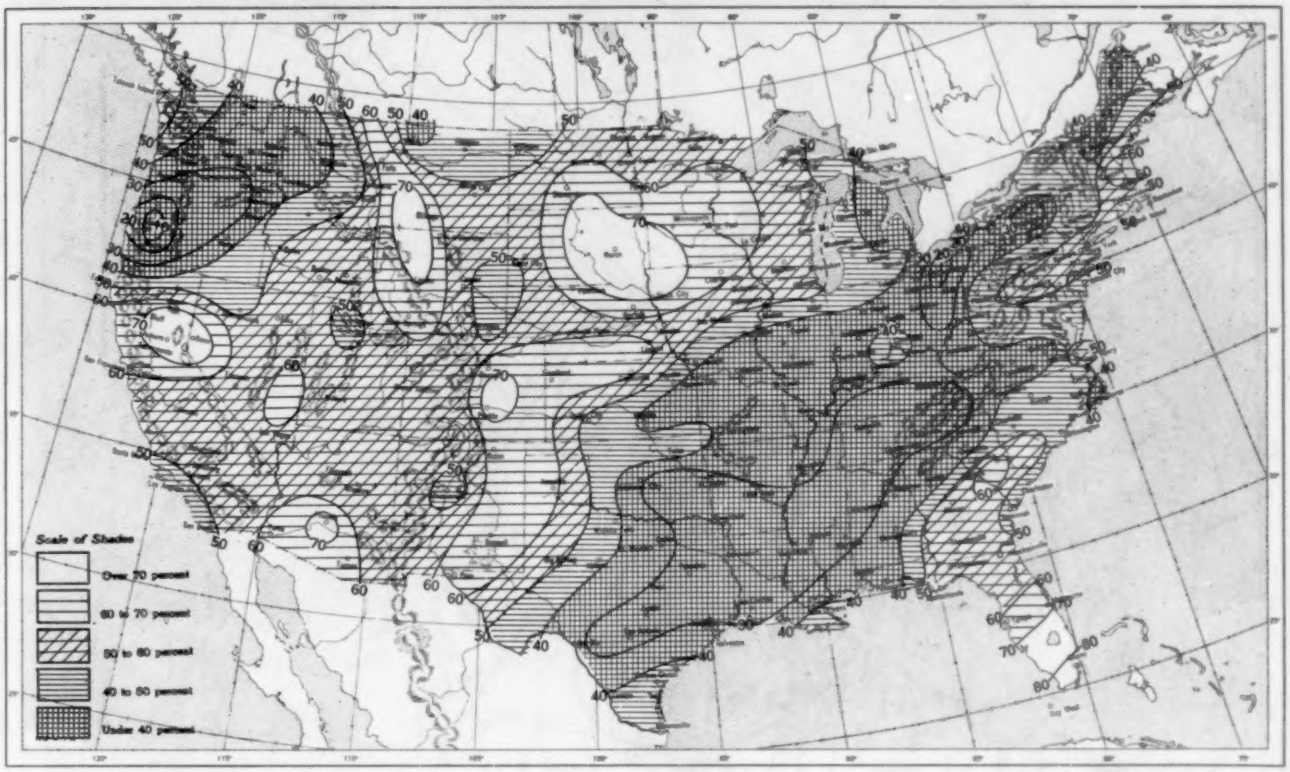


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, January 1957.

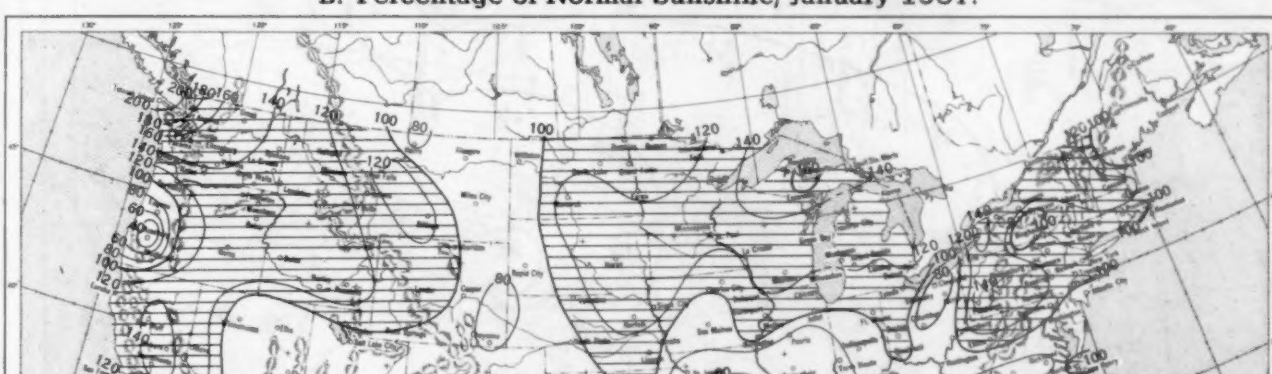


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, January 1957.



B. Percentage of Normal Sunshine, January 1957.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, January 1957. Inset: Percentage of Mean Daily Solar Radiation, January 1957. (Mean based on period 1951-55.)

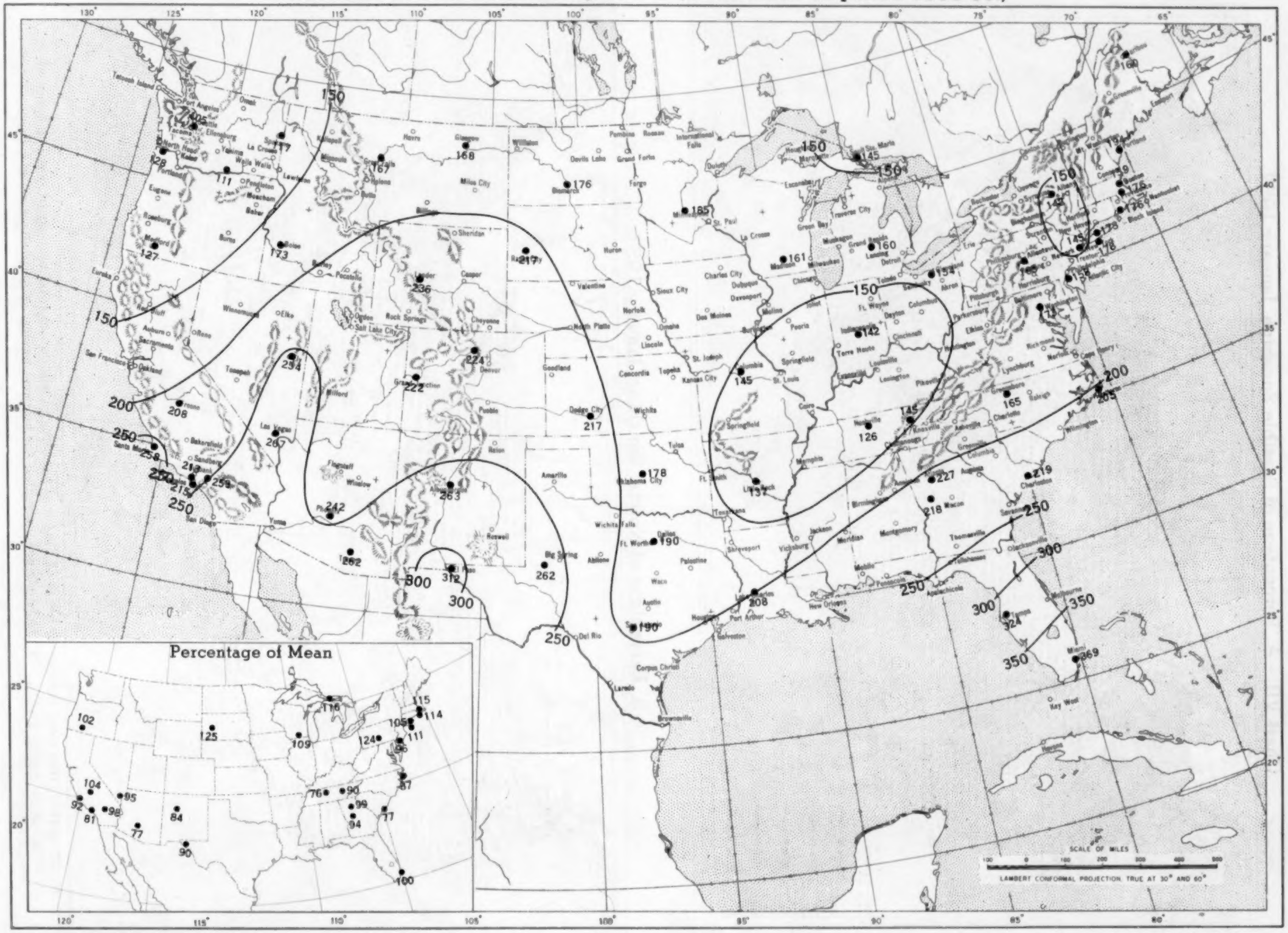
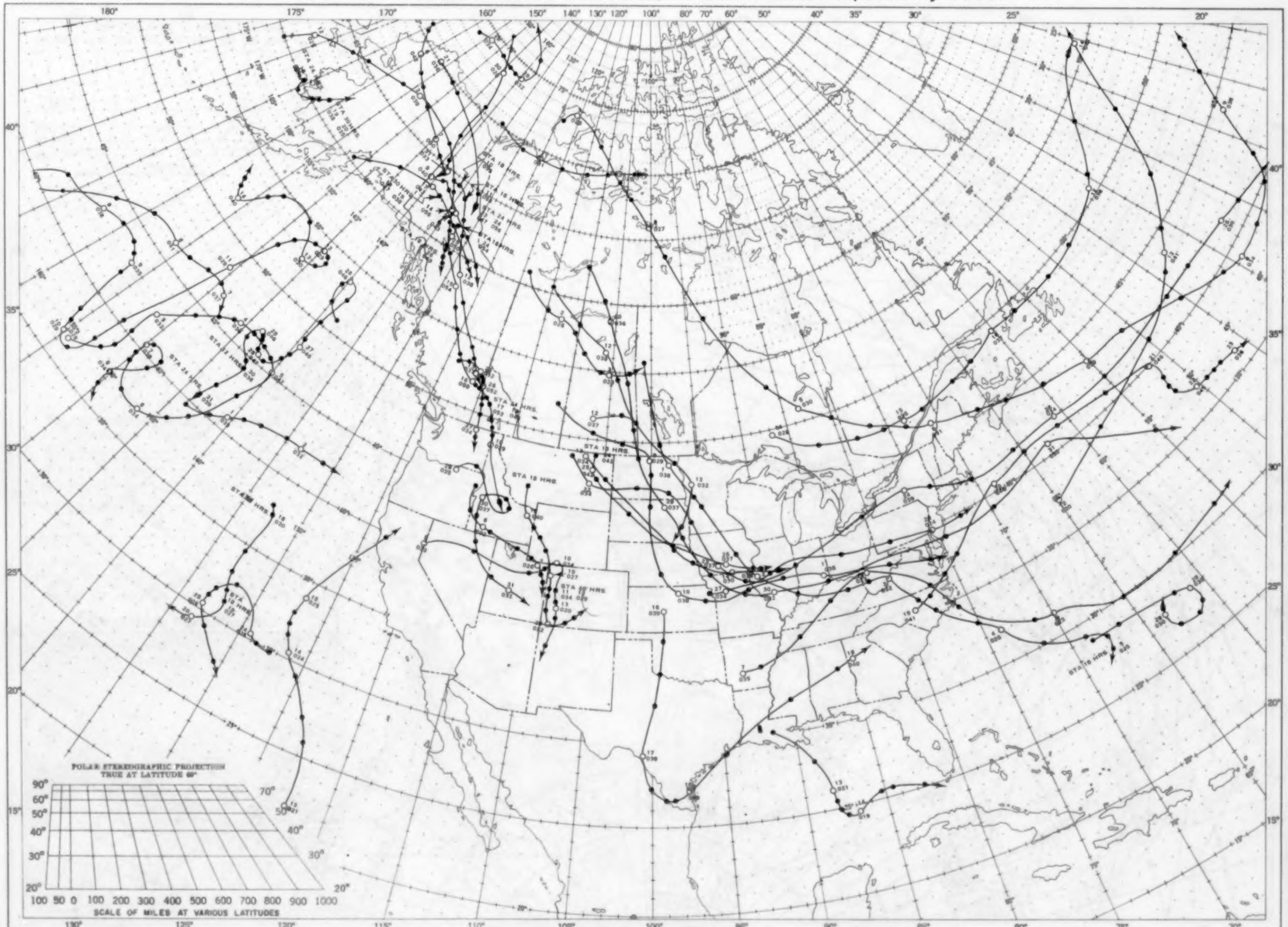


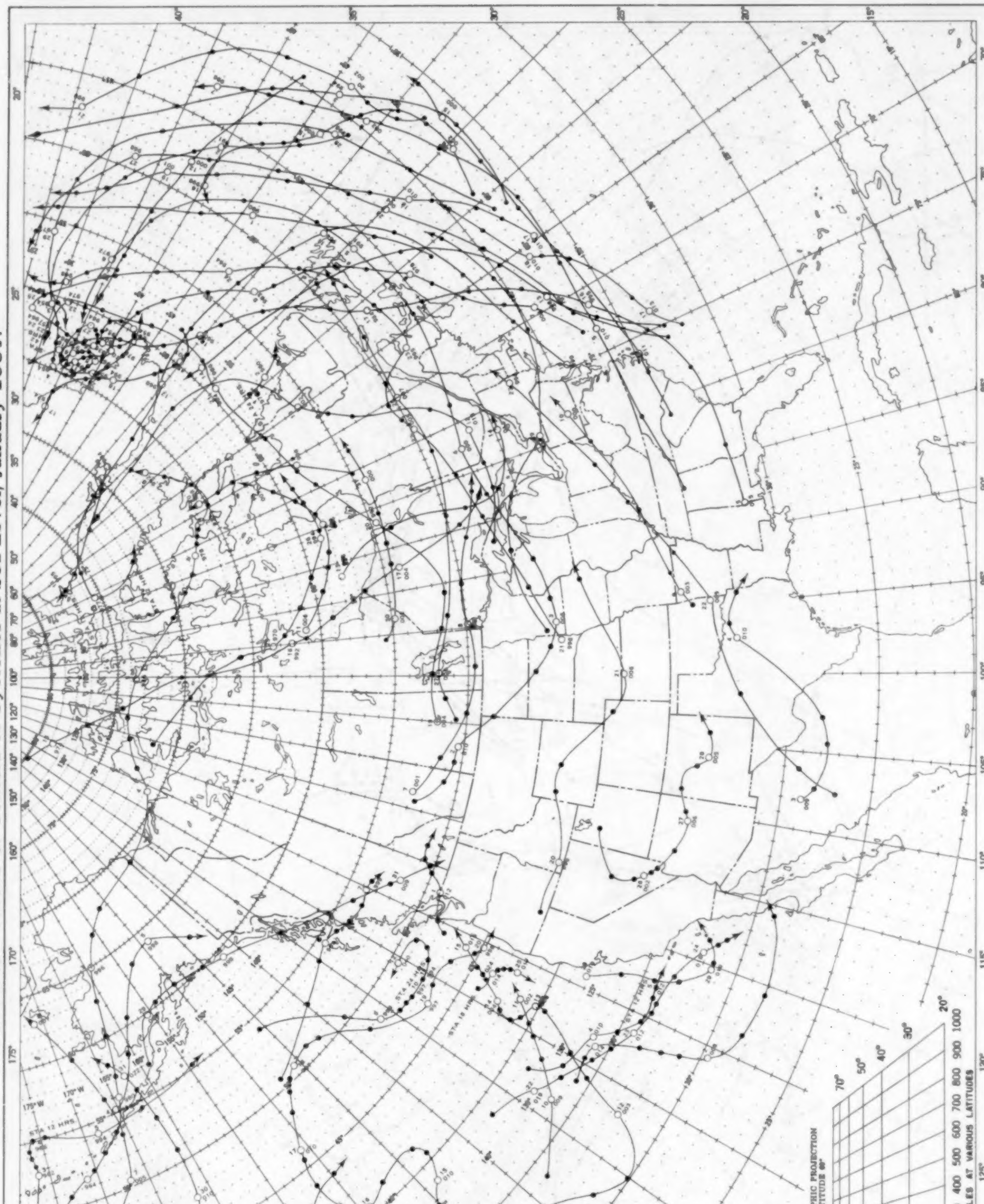
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm.$^{-2}$). Basic data for isolines are shown on chart. Further estimates are obtained from supplementary data for which limits of accuracy are wider than for those data shown.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, January 1957.



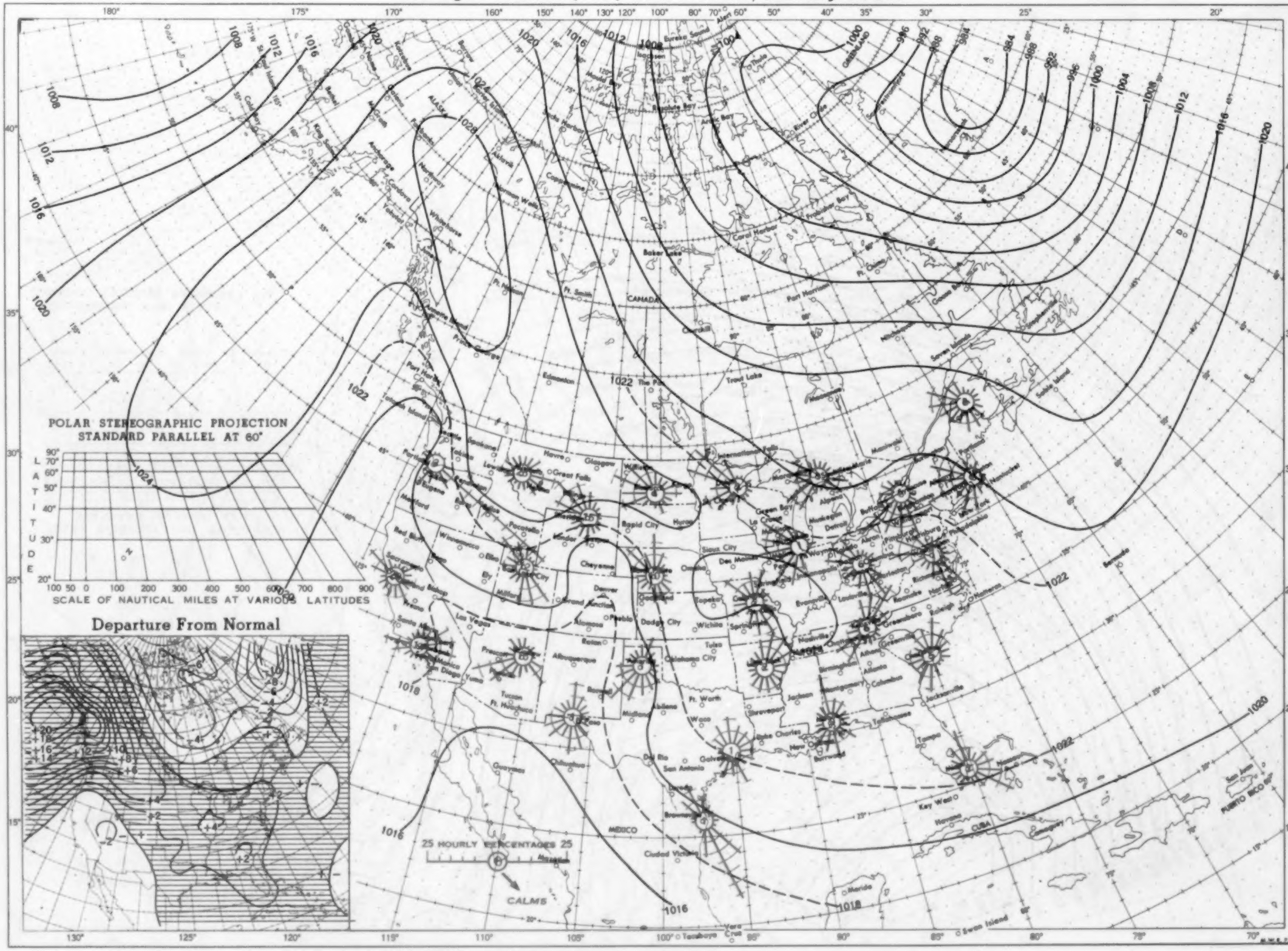
Circle indicates position of center at 7:30 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, January 1957.



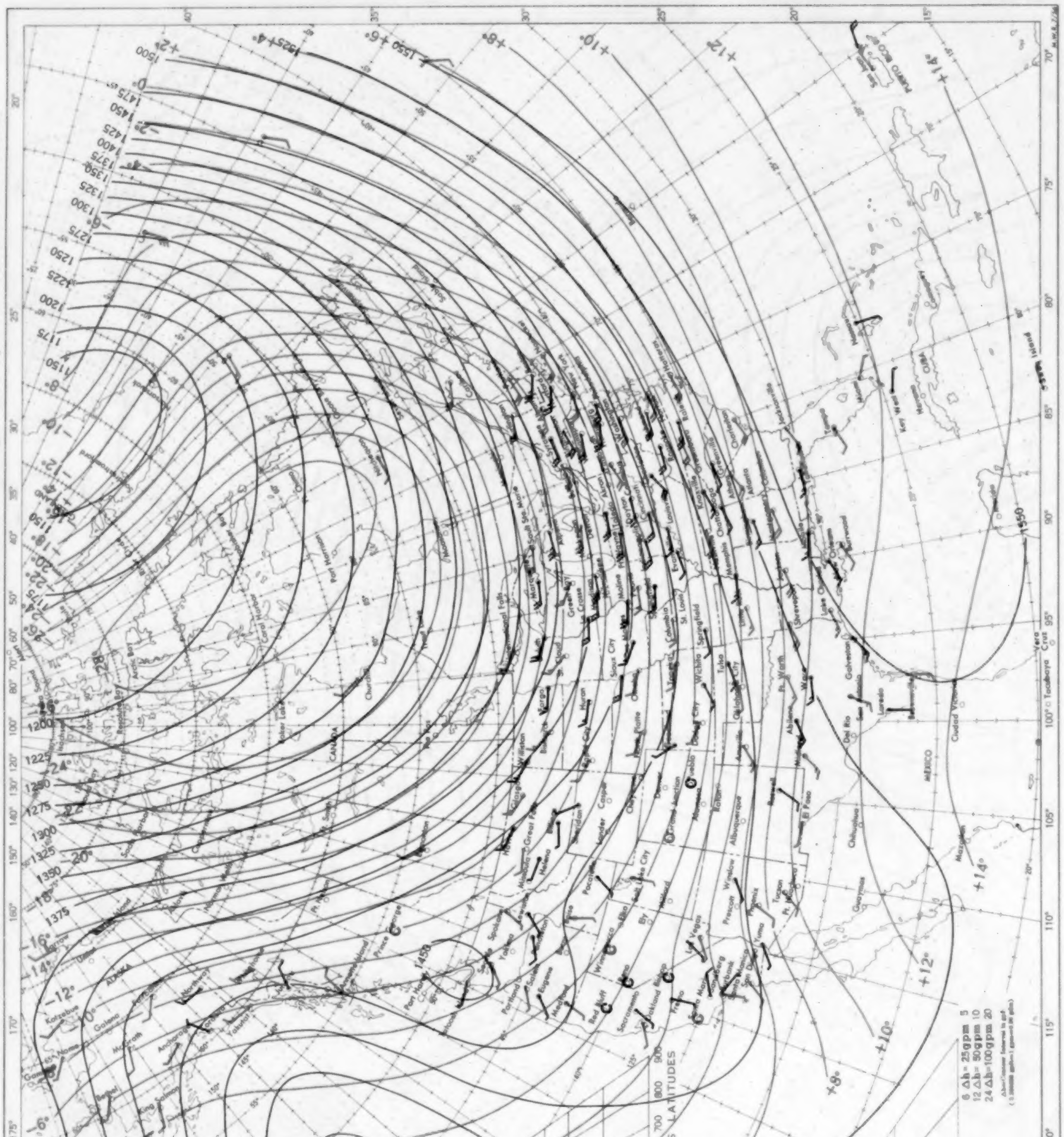
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, January 1957. Inset: Departure of Average Pressure (mb.) from Normal, January 1957.



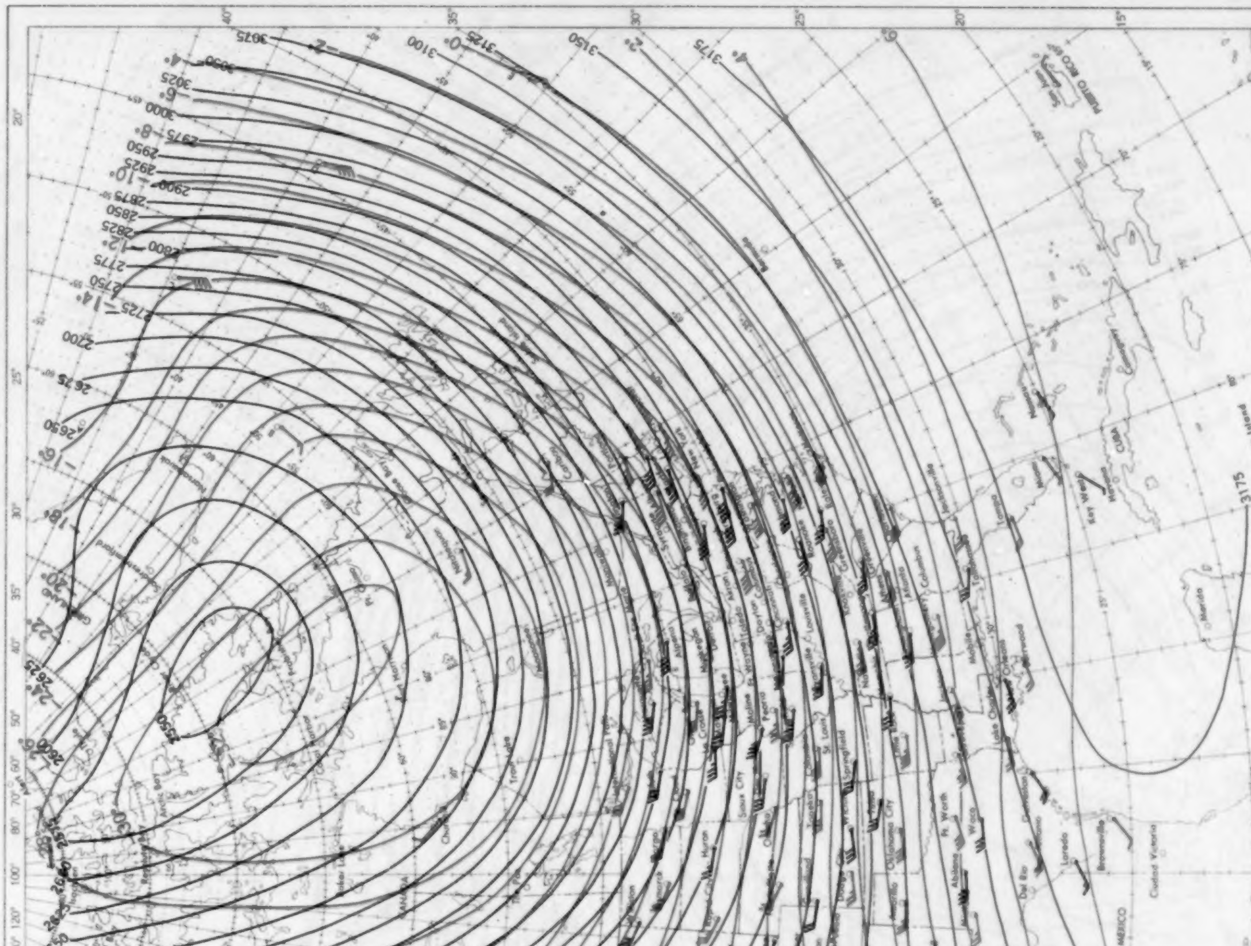
Average sea level pressures are obtained from the averages of the 7:30 a. m. and 7:30 p. m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

Chart XII. 850-mb. Surface, 0300 GMT, January 1957. Average Height and Temperature, and Resultant Winds.



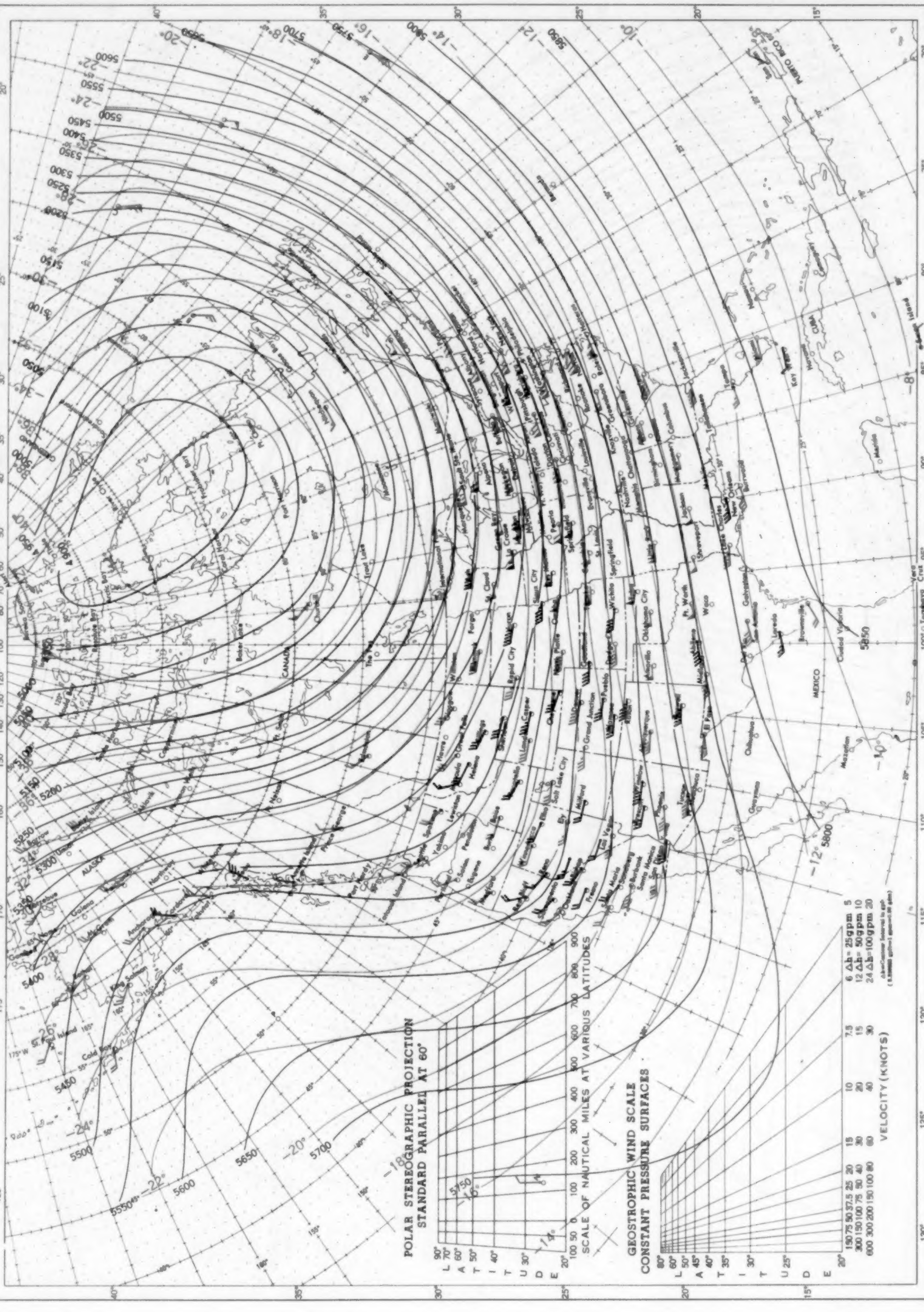
Height in geopotential meters (1 g.p.m. = 0.98 dynamic meters). Temperature in °C. Wind speed in knots; flag represents 50 knots, full feather 10 knots, and half feather 5 knots. Winds shown in red are based on rawins taken at the indicated pressure surface and time. Those in black are based on pibals taken at 2100 GMT and are for the nearest standard height level.

Chart XIII. 700-mb. Surface, 0300 GMT, January 1957. Average Height and Temperature, and Resultant Winds.



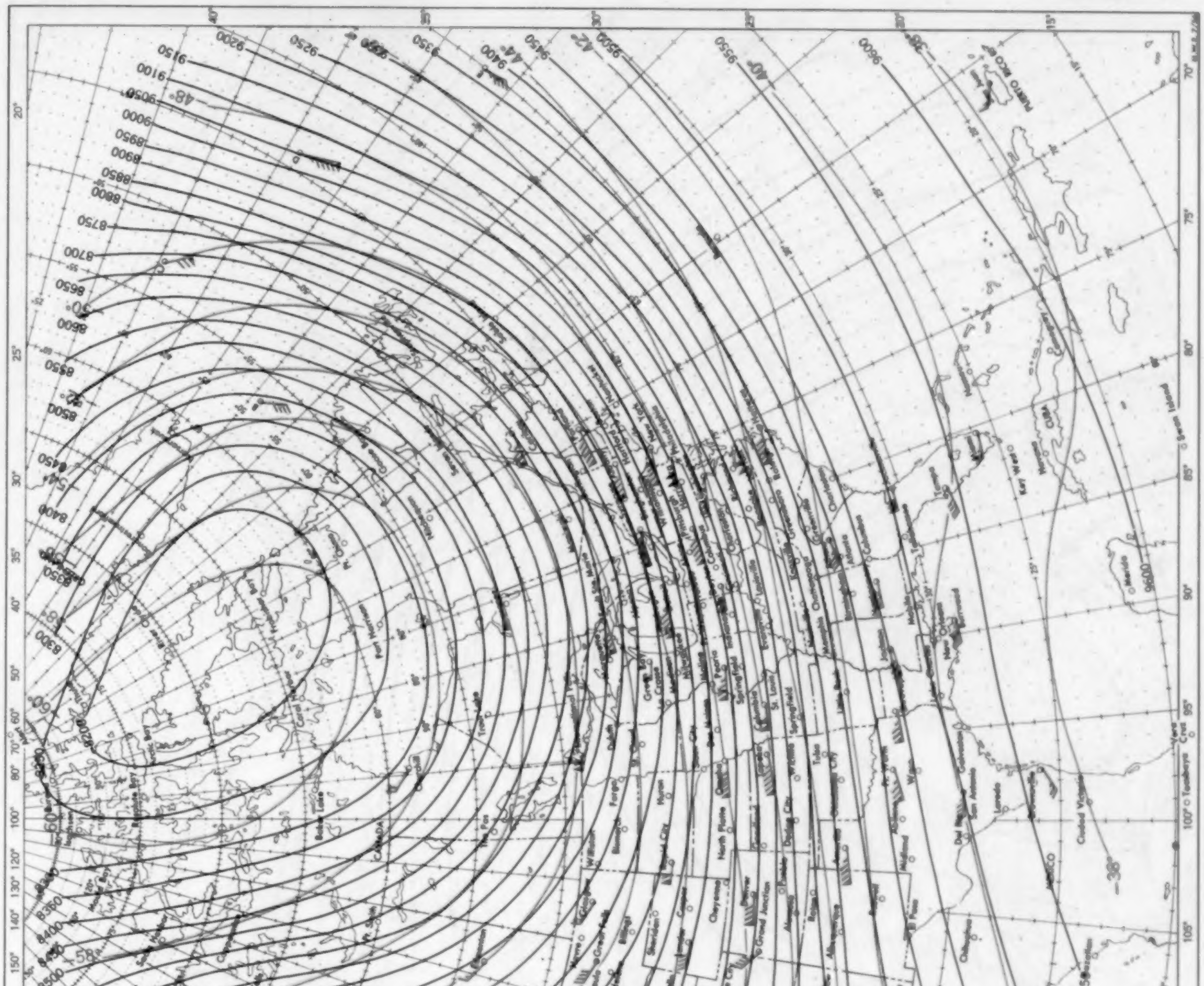
See Chart XII for explanation of map.

Chart XIV. 500-mb. Surface, 0300 GMT, January 1957. Average Height and Temperature, and Resultant Winds.



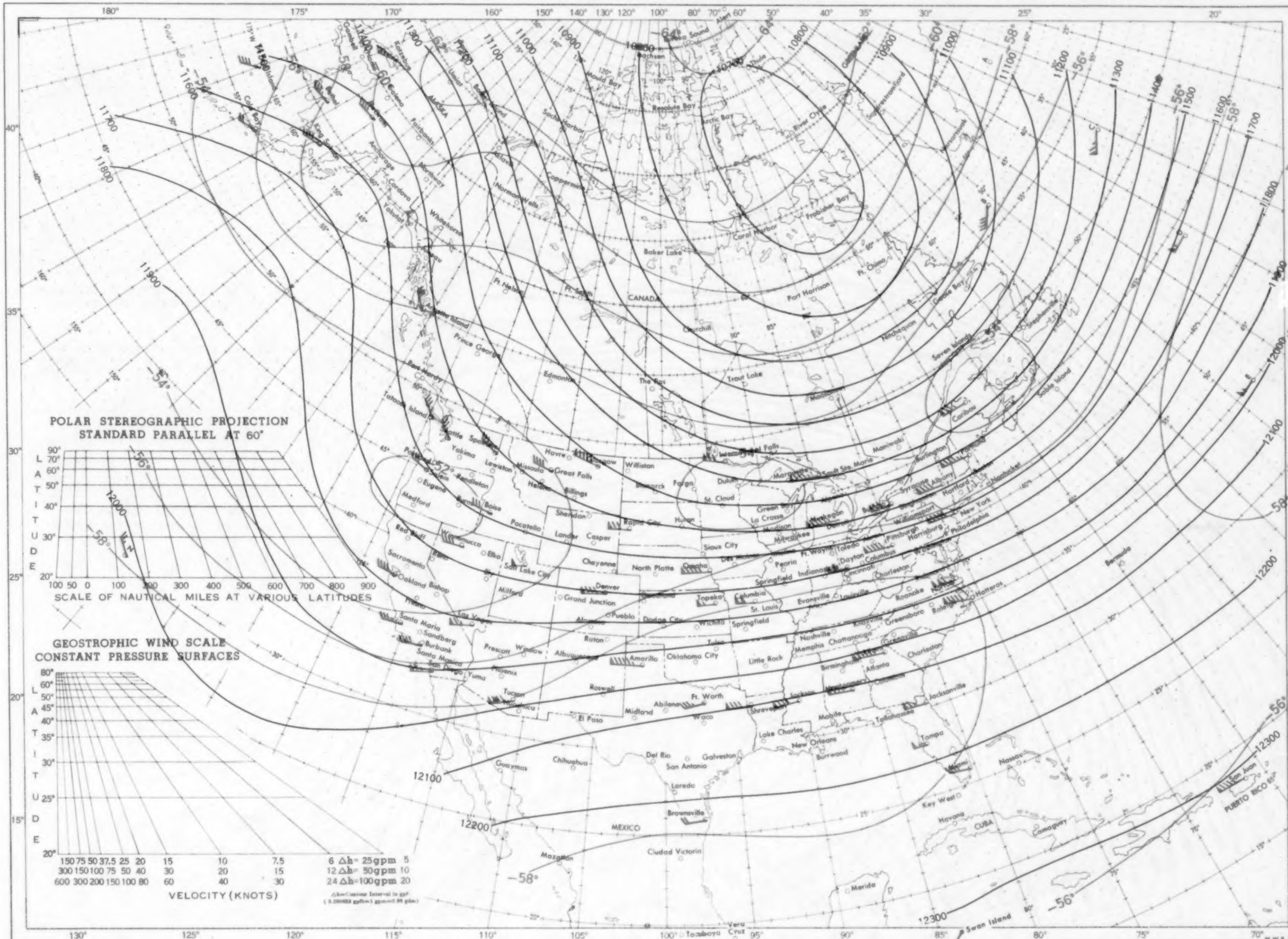
See Chart XII for explanation of map.

Chart XV. 300-mb. Surface, 0300 GMT, January 1957. Average Height and Temperature, and Resultant Winds.



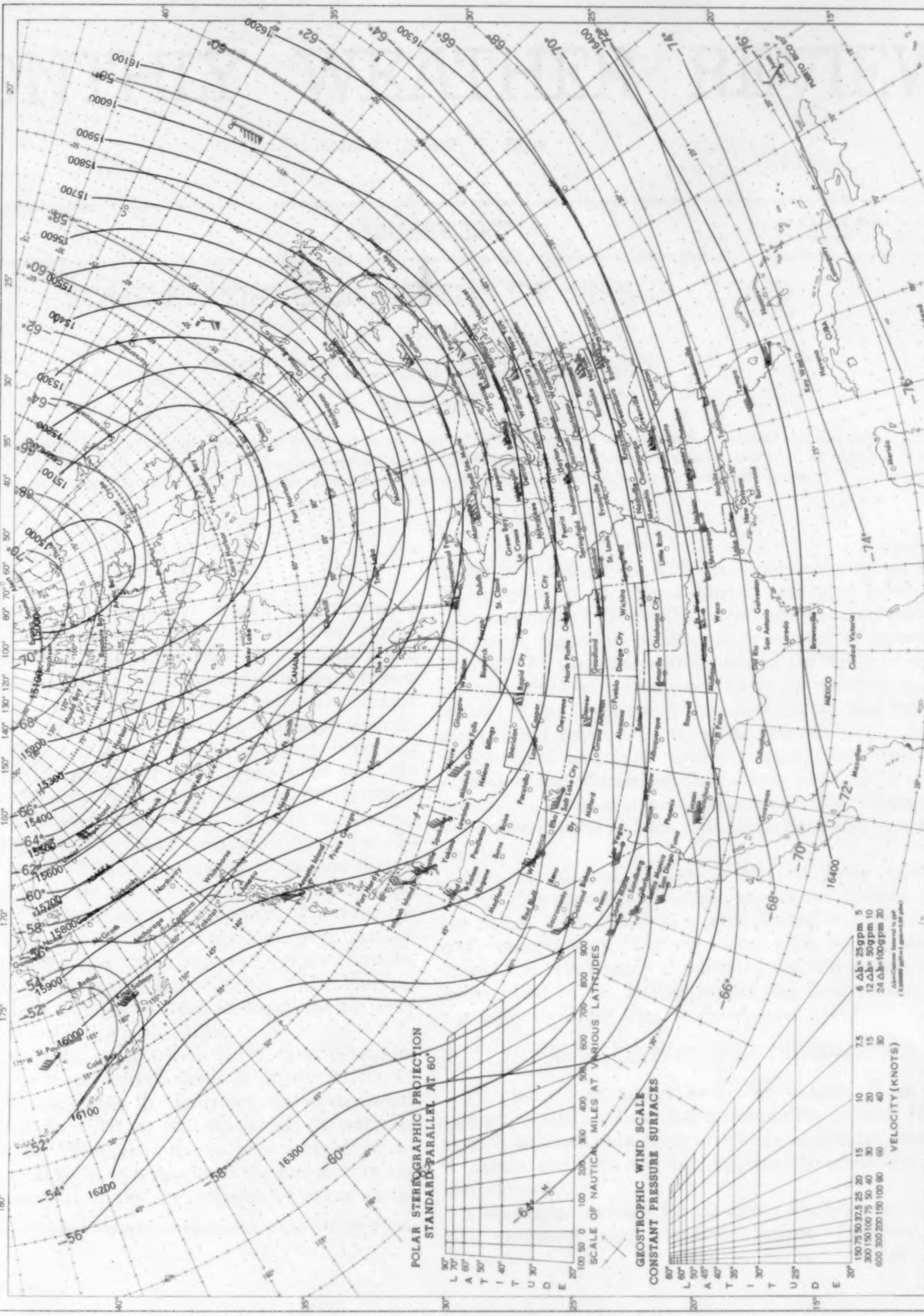
See Chart XII for explanation of map.

Chart XVI. 200-mb. Surface, 0300 GMT, January 1957. Average Height and Temperature, and Resultant Winds.



See Chart XII for explanation of map. All winds are from rawin reports.

Chart XVII. 100-mb. Surface, 0300 GMT, January 1957. Average Height and Temperature, and Resultant Winds.



See Chart XII for explanation of map. All winds are from rawin reports.